PHOTOGRAPH THIS SHEET

LEVEL

INVENTORY

1

Feasibility of Lighter-Than-Air Vehicles for Strategic mobility

DOCUMENT IDENTIFICATION

April 1988

DISTRIBUTION STATEMENT A

Approved for public release
Distribution Unlimited

DISTRIBUTION STATEMENT

ACCESSION FOR	
NTIS GRA&I	☑
DTIC TAB	☐
UNANNOUNCED	☐
JUSTIFICATION *per ltr*	

BY		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A-1		

DISTRIBUTION STAMP

DTIC
ELECTE
OCT 2 3 1989
S D
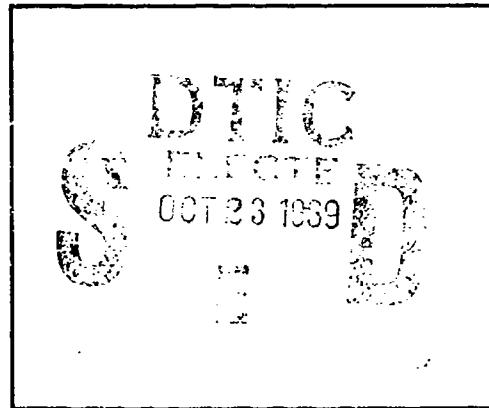
DATE ACCESSIONED

DATE RETURNED
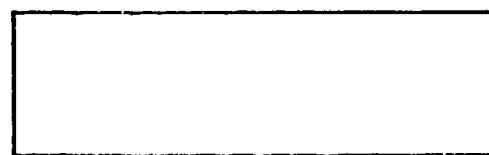
DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NO.

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

DTIC FORM 70A
MAR 86

DOCUMENT PROCESSING SHEET

PREVIOUS EDITION MAY BE USED UNTIL
STOCK IS EXHAUSTED.

FEASIBILITY OF LIGHTER-THAN-AIR VEHICLES

FOR STRATEGIC MOBILITY

by

Bruce John Gasper

A thesis

submitted in partial fulfillment

of the requirements for the degree of

Master of Transportation Engineering

in the Department of Civil Engineering

Seattle University

April 1988

MASTER'S PROJECT

In presenting this project in partial fulfillment of the
requirements for a Master's Degree at the Seattle University,
I agree that the Library shall make its copies freely available
for inspection. I further agree that extensive copying of this
project is allowable only for scholarly purposes. It is under-
stood, however, that any copying or publication of this project
for commercial purposes, or for financial gain, shall not be
allowed without my written permission.

Signature *[signature]*

Date 29 Mar 88

DEFENSE LOGISTICS AGENCY
DEFENSE TECHNICAL INFORMATION CENTER
CAMERON STATION
ALEXANDRIA, VIRGINIA 22304-6145

OFFICE OF THE ADMINISTRATOR

26 Sep 89

Mr. Gasper,

The thesis you have submitted to us is copyrighted and
therefore cannot be entered into our database until the copy-
right and all rights reserved have been released. In order
for the thesis to be entered you will have to send a letter
stating your written consent for the releasal of the copy-
righted thesis and whatever distribution statement you want
the thesis to be under. (See attached letter) We appreciate
all assistance you will be able to give us in this matter.

Thank You,
DTIC-FDAC

2 Encl

1st Ind, 7456 TIS/INTM
TO: DTIC-FDAC

My copyright for "Feasibility of Lighter-Than-Air Vehicles
for Strategic Mobility" is released and permission is
granted to DTIC to copy the manuscript. Distribution is
approved for public release.

BRUCE J. GASPER, Maj, USAF
Chief, Target Materials and Unit Support Division

TABLE OF CONTENTS

iii

TABLES

FIGURES

ACKNOWLEDGMENTS

DISCLAIMER

The views and opinions expressed in this document represent the personal views of the author only, and should not in any way be construed to reflect any endorsement or confirmation by the Department of Defense, the Department of the Air Force, or any other agency of the U.S. Government.

xi

CHAPTER 1

Introduction

Background

U.S. interests and commitments worldwide are protected through a strategy called forward defense. This strategy is broken down into two concepts: forward basing and reinforcement. Forward basing is the positioning of U.S. military forces in foreign countries. It demonstrates America's national interest in the region and reduces response time should conflicts break out; but it is expensive in military and economic terms. Because they are bound by treaties with host nations, forward based forces often lose their flexibility to respond to crises in other parts of the world. Monetary costs to support forward based forces are high due to the extensive logistics pipeline required and leases on property and facilities (11:41-1).

Reinforcement is the concept of augmenting forward bases with forces from the U.S., or sending U.S. forces into a region where no forward base exists. The advantage of reinforcement is that U.S.-based forces have the flexibility to respond worldwide and the capability to determine response intensity, both of which act as deterrents by complicating an enemy's planning. Another advantage is that reinforcement is the cost effective complement of forward basing. A disadvantage of reinforcement is that it requires an extensive and expensive transportation system, which in turn requires a significant amount of time to move personnel and materials to the region of conflict (11:41-2).

During mobilization, U.S. military forces must be rapidly moved from U.S. bases either to reinforce forward bases or to establish new bases in the region of conflict. Mobilization will require massive amounts of airlift initially and later will require both airlift and sealift. Budget priorities, among other factors, have resulted in a strategic airlift fleet that can not fulfill the mission assigned to it. In 1984, the strategic airlift capability was less than 50 percent of the goal (56:45), and this goal will certainly increase if U.S. naval forces lose control of the seas (32:48). Problems with strategic airlift are well documented (32:ii), i.e. cargo capability shortfalls, uncertain nature of staging and refueling bases, and high fuel costs.

Recent advances in the aerospace industry have led to proposals for lighter-than-air vehicles (LTAV) over 1,200 feet long, with volumes greater than forty million cubic feet and lift capabilities of hundreds of tons (14:13-14; 32:26). Current technology, as applied to LTAV may offer the military an efficient complement to the present strategic mobility fleet of ships and airplanes.

Purpose

The purpose of this study is to determine whether conventional rigid lighter-than-air vehicles with a range of 8,000 miles are feasible for supporting strategic mobility. The basis for the conventional rigid approach is design efficiency and cost effectiveness, and will be discussed later in this paper. The 8,000 mile range will allow the LTAV to reach the critical regions of the world where U.S. forces may need to be deployed. Characteristics and performance of a

proposed LTAV will be compared to current cargo airplanes which will be the standard used to determine feasibility of strategic mobility lighter-than-air vehicles.

Methodology and Limitations

This study will be an analysis of research in the field of aerospace technology, lighter-than-air vehicles, and strategic mobility vehicle requirements. Chapter 1 includes a review of fundamental concepts involving lighter-than-air vehicles and their design. This chapter also presents a short history of lighter-than-air vehicles. Chapter 2 discusses management of strategic mobility assets and the requirements for strategic mobility. Chapter 3 presents technical problems and vulnerabilities that airships have encountered in the past and problems that may confront a modern LTAV. Potential solutions to these problems are also presented. Economic and cost figures are presented in Chapter 4. Chapter 5 examines a potential LTAV to meet prerequisites addressed throughout this study. A summary is presented in Chapter 6, along with recommendations.

This study is not intended to be highly analytical in the engineering sense; rather it is intended to determine if new technologies or operations can be applied to make the LTAV a feasible and effective heavy lift vehicle. The vehicle to be studied will be a conventional rigid airship. In defining the operating environment for the LTAV, only conventional (i.e. non-nuclear, non-chemical, and non-biological) confrontations will be considered. Also, due to public apprehension regarding nuclear energy, nuclear powered lighter-than-air vehicles

will not be considered, although the subject is covered extensively in other sources.

Background of Lighter-Than-Air Vehicles

Principles of Lift

Lighter-than-air vehicles derive their ability to remain airborne from aerostatic forces rather than from aerodynamic forces as airplanes do. Aerostatic force is explained by Archimedes' Principle which states that "a body immersed in a fluid is buoyed up with a force equal to the weight of the displaced fluid (81:23)." In other words, if the total weight of the airship is less than the weight of the air it displaces, then the airship will rise. Lift is a term synonymous with aerostatic and aerodynamic forces.

Types of Airships

There are three types of conventional lighter-than-air vehicles. The first is the nonrigid type, or blimp, made from a gas cell whose external shape is maintained solely by the pressure of the lifting gas in the cell. The second type of airship is the semirigid type which is similar to the nonrigid airship except that a rigid keel is used to add structural support to the vehicle. The third type is the rigid airship (or zeppelin) whose shape is maintained by an extensive rigid framework inside the envelope (59:7). In addition to the conventional types of airships, there are also hybrids which include rotating spheres, delta-shaped vehicles, combination airship/helicopters, and other designs. Figure 1 shows airship classification among aircraft.
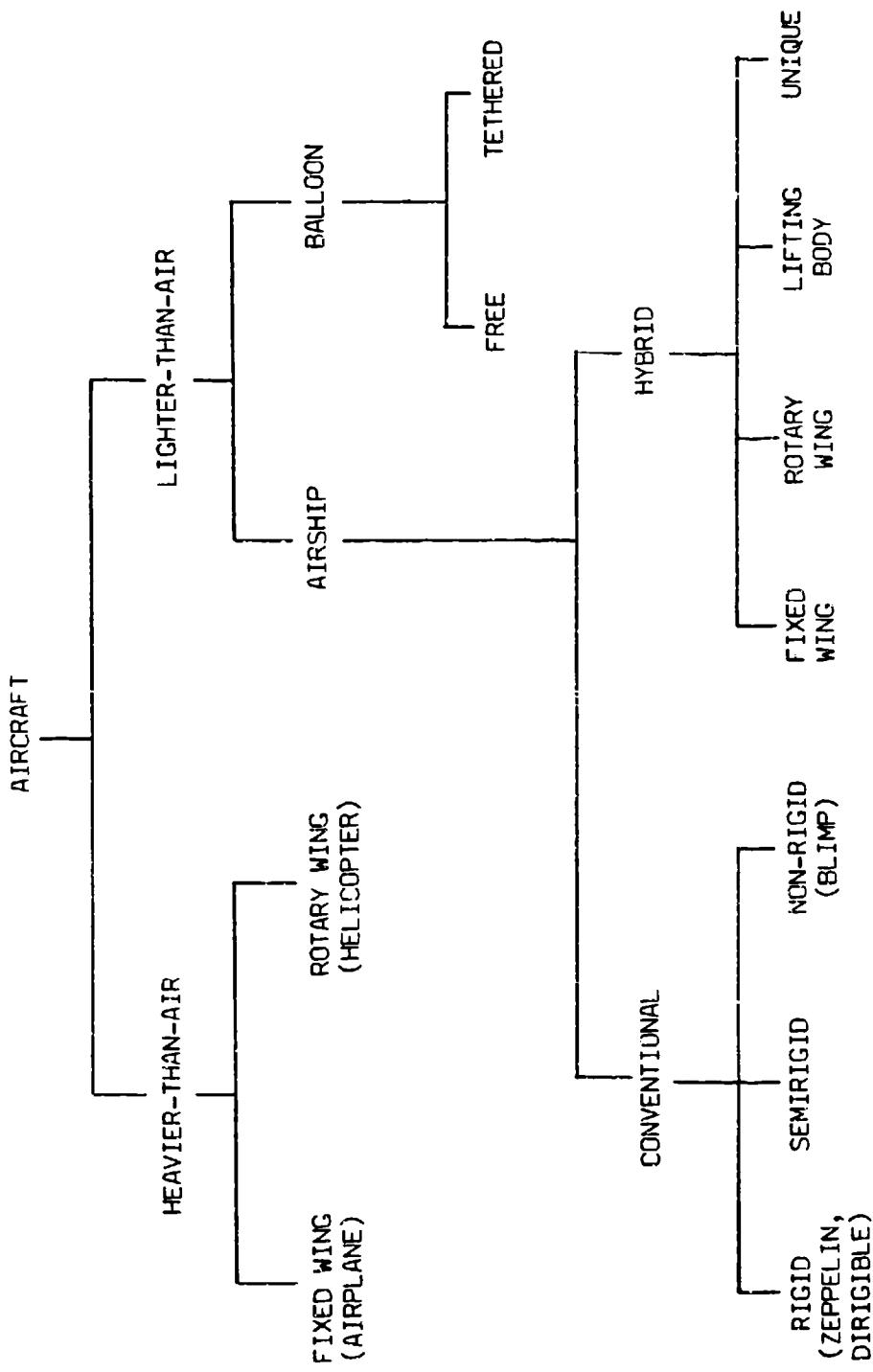
Figure 1

Aircraft Classification

This study will only examine the conventional rigid airships due to the lower cost associated with development of a previously designed system, and because the rigid airship offers the best structural efficiency at large gross weights (12:122). It is anticipated that hybrid type airships will require a larger initial capital investment due to the lack of operational experience. Most hybrid airships require further study because they face significant aerodynamic interactions that are not considered a problem in conventional airships (72:425).

Parts of the Airship

The largest part of the conventional airship is the hull. The hull contains the gas cells, primary structures, crew quarters, fuel, and payload. The fins are attached to the rear of the hull; they provide control surfaces for changing heading or pitch. The control car, or gondola, is attached to the bottom of the hull just behind the nose. Some early airships had an aft steering station located in the lower vertical fin. Engine gondolas, or nacelles, were attached externally to the hull. Some airships had the engines inside the hull with a shaft protruding from the engine through the hull to the propeller. Figure 2 shows the external features of a conventional rigid airship.

The shape of the conventional rigid airship is maintained by a series of rings attached to girders. The rings, or frames, form the cross section of the airship. Main frames are cross-wired to provide rigidity to the hull structure and form bulkheads between adjacent gas cells. Intermediate frames do not have the cross-wiring which allows space for the gas cells. The longitudinal girders run from the nose to
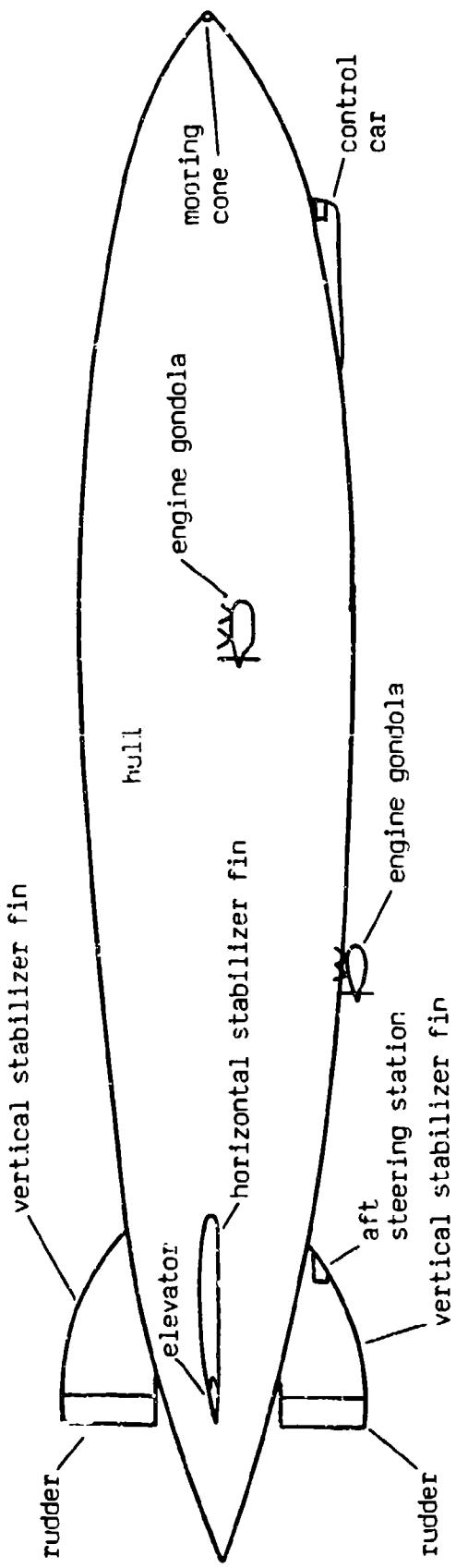
Figure 2

External Structures of a Conventional
Rigid Airship

Source: 13:104-05

the tail and attach to the main and intermediate frames. Additional strength is obtained from wires, called shear wires, that run diagonally in the quadrilateral panels formed by the intersection of the frames and the longitudinal girders (16:4-5; 22:26). Figure 3 shows the internal construction of the hull.

History of Lighter-Than-Air Vehicles

By examining the history of lighter-than-air vehicles, this study will attempt to identify common airship problems and determine how such problems could now be avoided by applying modern technology. It will also examine operating procedures to determine if tasks can be done more efficiently.

"From man's first documented flight to his first walk on the moon was less than 186 years (64:8)." Man's first documented flight was made by two Frenchmen on 21 November 1783 using a balloon designed and built by the Montgolfier Brothers. The first lifting gas was hot air; a month later hydrogen came into use. In 1851, another Frenchman, Henri Giffard, invented a lightweight steam engine suitable for use in airships. Engines and propellers allowed airships to be steered, and soon, airships became streamlined to permit more efficient movement (59:7; 64:9). The advent of propulsion systems was followed by a very productive period in the development of lighter-than-air vehicles.

In 1900, Count Ferdinand von Zeppelin launched his first of over one hundred rigid airships. Count von Zeppelin's airship company became the driving force in lighter-than-air progress throughout the world for almost the next four decades (22:19; 64:9). In the United

Lifting Gas Cell

Main Frame

Longitudinal Girder

Main Frame Cross Wire

Intermediate Frame

Shear Wires

Water Condensers

Propeller and Drive Shaft

hull
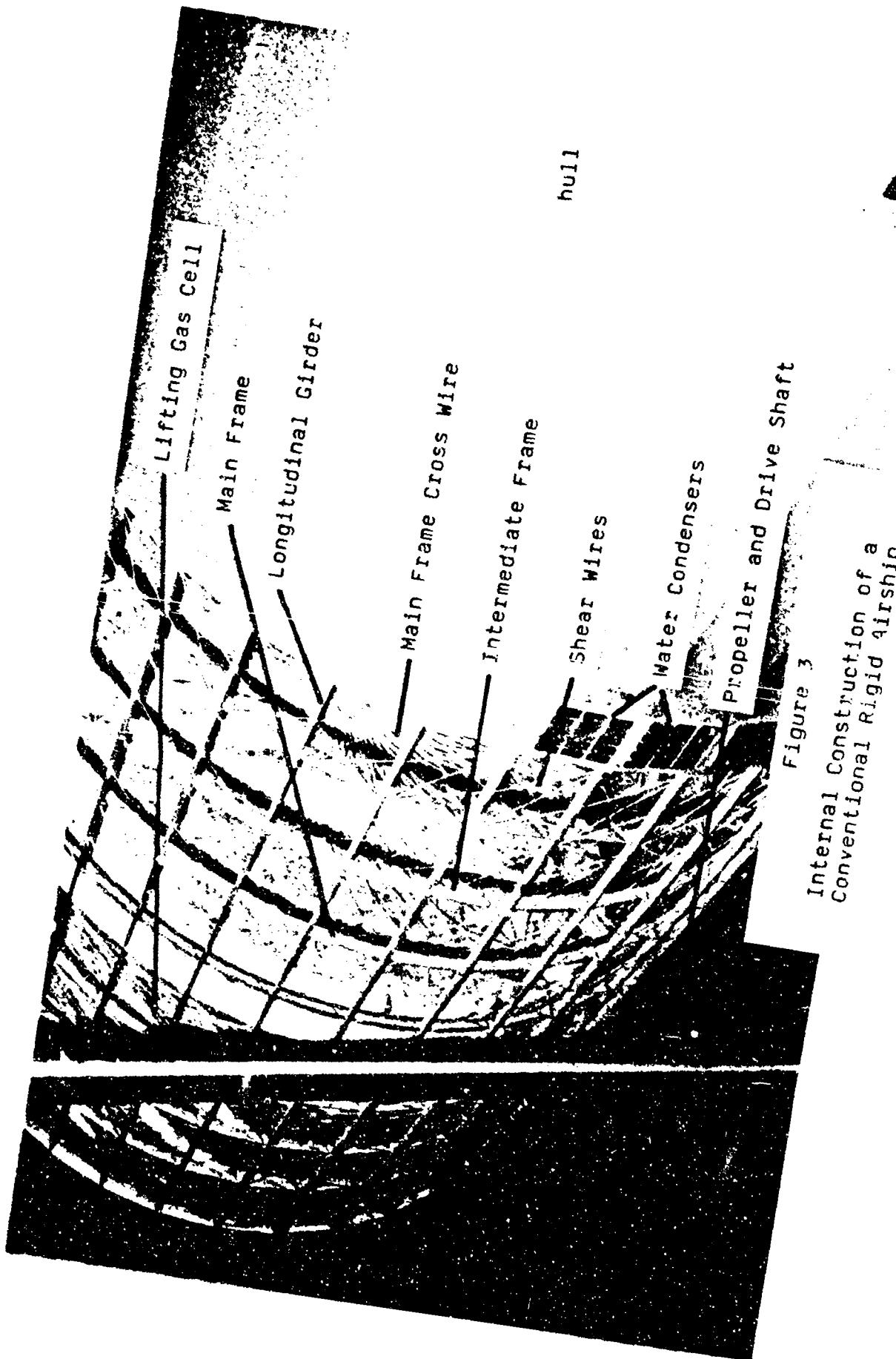
Figure 3

Internal Construction of a
Conventional Rigid Airship

9

States, the Goodyear Tire and Rubber Company began building nonrigid
airships in 1911 (64:11-12). In the early 1900s, both the U.S. Army
and the U.S. Navy used airships, which at the time, had ten times the
range of airplanes and three times the speed of surface ships (24:57).

> Prior to World War I airship design, construction, and use
> met with varying degrees of success in England, France,
> Italy, Russia, the United States, and Germany. Only Germany,
> however, under the impetus provided by Zeppelin, made exten-
> sive use of the airship as an offensive weapon, bombing
> targets in England from as high as 20,000 feet (64:9).

During World War I (WWI), thousands of airship missions were flown
by both sides (14:45; 64:9-10). The explosive hydrogen lifting gas
made the airships too vulnerable, and fifty-one were lost due to
military action. One of the most impressive and unique, although least
known, airship missions of WWI was the flight of the German Zeppelin
L59 on 16 November 1917. The L59, loaded with fifty tons of supplies,
flew 4,200 miles in ninety-five hours in an attempt to resupply German
troops in Africa. Unfortunately the airship did not complete its
resupply mission because the troops surrendered before the airship
arrived (9:92,121). That famous flight of the L59 was the first
recorded attempt at strategic airlift.

After the war, airship activity in England, France, and Italy was
abandoned due to a series of airship disasters. On the other hand,
research and development activity in Germany pushed the technology to
higher levels. Unfortunately, German airship operations were prohib-
ited by the postwar armistice agreement (64:9-11).

The U.S. Army had purchased a semirigid hydrogen-filled airship,
the Roma, from Italy. In 1922 it hit high tension electrical lines and

exploded killing thirty-four of its forty-five man crew. As a result, the decision was made that all U.S. airships would use helium, an inert lifting gas that the U.S. had a monopoly on at that time. In 1920, the U.S. government asked Goodyear to develop a rigid airship similar to the German zeppelins. Goodyear began negotiations with the erman airship company founded by von Zeppelin, and by 1924 an agreement was reached that gave Goodyear process and patent rights to build airships similar to the German zeppelins. At the same time Goodyear began development of two large rigid airships for the Navy, the U.S.S. Akron and the U.S.S. Macon.

Both of these Navy airships were 785 feet long and 133 feet in diameter. They were flying aircraft carriers, each with a crew of ninety-nine, three airplanes, and an available deck area of 12,000 square feet, almost three times that of a Boeing 747 (22:38). In 1925, while the Akron and Macon were still in the design stages, the first American-built zeppelin-type airship, the U.S.S. Shenandoah, crashed in severe weather killing fourteen of its crew. Around the same time, the U.S.S. Los Angeles had arrived from Germany; it eventually flew a total of 4,320 hours and was decommissioned in 1932 after setting an out-standing safety record for large rigid airships in the U.S. Shortly before the Los Angeles had been decommissioned, the Akron was launched. Seventeen months later, however, the Akron crashed off the coast of New Jersey, resulting in the loss of seventy-two lives. Its sistership, the Macon, was commissioned during the same month the Akron disaster occurred. It flew for almost two years before it too crashed (64:13).

The Germans were permitted to resume airship operations in 1925 (64:10) and shortly afterwards they impressed the world with the airship Graf Zeppelin. The Graf Zeppelin was used for exploration in addition to cargo and passenger services. Before it retired in 1937 with nine years of service, the Graf Zeppelin had crossed the Atlantic 144 times. It had flown over 16,000 hours on 590 flights while carrying more than 13,000 passengers. The Graf Zeppelin was the first aircraft ever to fly more than one million miles (13:164). It once flew around the world in just under twenty-one days (3:27; 33:56; 64:10). Compared to today's standards, the Graf Zeppelin did nothing extraordinary but during its time it was unsurpassed in aerial transportation.

While the Graf Zeppelin was making aviation history, the larger German airship, the Hindenburg, was launched. It was a luxury cruise ship in the sky; it even had a 397 pound aluminum piano on board for entertaining the passengers (32:23). The U.S., still with its monopoly on helium, cancelled plans to sell some of the nonflammable gas to Germany for the Hindenburg and its sistership, the Graf Zeppelin II. This was partially due to fears of war and also because U.S. airlines were about to begin transatlantic service which would have been in direct competition with the Hindenburg (9:171; 64:10-12). This set the stage for one of the most spectacular aviation disasters in history. On 6 May 1937, the 814 foot long Hindenburg, filled with seven million cubic feet of hydrogen, exploded and burned while docking at Lakehurst, New Jersey (14:32; 22:21; 45:46; 63:63). Between 1919 and 1937, the

German airship service had carried almost 52,000 passengers over 1.4 million miles without any passenger injury or fatality. The Hindenburg incident broke that record when thirteen passengers died. Including the twenty-two crew members who died, the fatality rate was about 30 percent (1:11; 22:32). Public outcry about airship disasters, coupled with advances in airplane technology, quickly led to the end of commercial airship activities as well as the end of rigid airships. Even the successful Graf Zeppelin and the Hindenburg's new sistership were quickly retired. Table 1 lists the number of rigid airships built compared to the total number built for the five countries primarily involved in airship activities. Russia is known to have had airships but details are difficult to confirm.

Table 1

Airship Construction, 1900 -- Present

Country	Number of Rigid Airships	Total Number of Airships
France	1	26
Germany	152	159
Great Britain	16	28
Italy	0	14
United States	3	448
Total	172	675

Source: 1:10

After the Hindenburg disaster, the only airships used in the U.S. were Goodyear and Navy blimps. During World War Two (WWII), 164 U.S. Navy blimps performed convoy escort, surveillance, mine laying and sweeping, search and rescue, and antisubmarine warfare duties (63:63). The Navy claims that none of the 89,000 ships escorted by their blimps were ever lost to enemy action (33:57).

After WWII, the Navy used its blimps for antisubmarine warfare and airborne early warning against bomber attacks. In 1957, a Navy ZPG-2 airship flew 9,400 miles in eleven days without refueling. I‹. 1958, the Navy launched its first ZPG-3W (see Figure 4), the largest nonrigid airship to ever fly (33:57). It was 403 feet long and carried a forty foot revolving radar antenna inside (24:57). When the threat to the U.S. shifted from bombers to intercontinental ballistic missiles, the airships became obsolete. Also, continuing progress in airplane technology overtook the airships. In 1961, forty years of reliable and safe Navy airship operations came to an end (63:64; 64:14). About the same time, airship interest in the Soviet Union reemerged, but progress apparently became bogged down in the bureaucracy (31:11).

New Developments in Lighter-Than-Air Transportation

Perhaps the most widely known airships are the Goodyear blimps. Each is 192 feet long and can carry up to seven people at speeds up to fifty miles per hour (59:6). These airships use very little advanced technology but are highly reliable and very safe (34:75). Additional companies have entered the lighter-than-air industry in recent years

15

Figure 4

U.S. Navy ZPG-3W, World's Largest Nonrigid Airship
Used for Airborne Early Warning Duties

Source: 21

due to the potential for military and commercial contracts for air-ships. The British firm, Airship Industries Ltd., has two versions of semirigid airships in commercial use with customers around the world. Their Skyship 500, a twelve passenger LTAV, "is considered the first attempt to combine the traditional blimp configuration with modern materials, power plants, and related systems" (34:75).

The U.S. Navy and U.S. Coast Guard have reviewed the potential benefits of lighter-than-air vehicles. A major study completed in 1980 by the Navy's Lighter-Than-Air Project Office concluded that airships have the potential to be used effectively in several maritime missions. They recognized several appealing attributes of airships: high energy efficiency and long endurance compared to airplanes, minimum support facilities requirements compared to both airplanes and surface ships, high speed compared to surface ships, and a large volume for required mission systems (34:73). However, it must be pointed out that the Navy and Coast Guard do not plan to use the airship for carrying extremely heavy payloads. Between 1982 and 1983, the services conducted success-ful tests with both the Goodyear Enterprise and a Skyship 500 (see Figure 5) (34:74-75). Even some of the large aerospace companies had bid for a piece of the Navy airship market; the Boeing Company had proposed a 534 foot long rigid airship (38:C9; 69:102, and the Lockheed Company had proposed a 504 foot long nonrigid airship (33:59). Airship Industries and Westinghouse teamed up and proposed a new airship about 350 feet long (8:106; 69:102), and Goodyear had proposed updating its 403 foot long 1950s vintage ZPG-3W design (24:57).
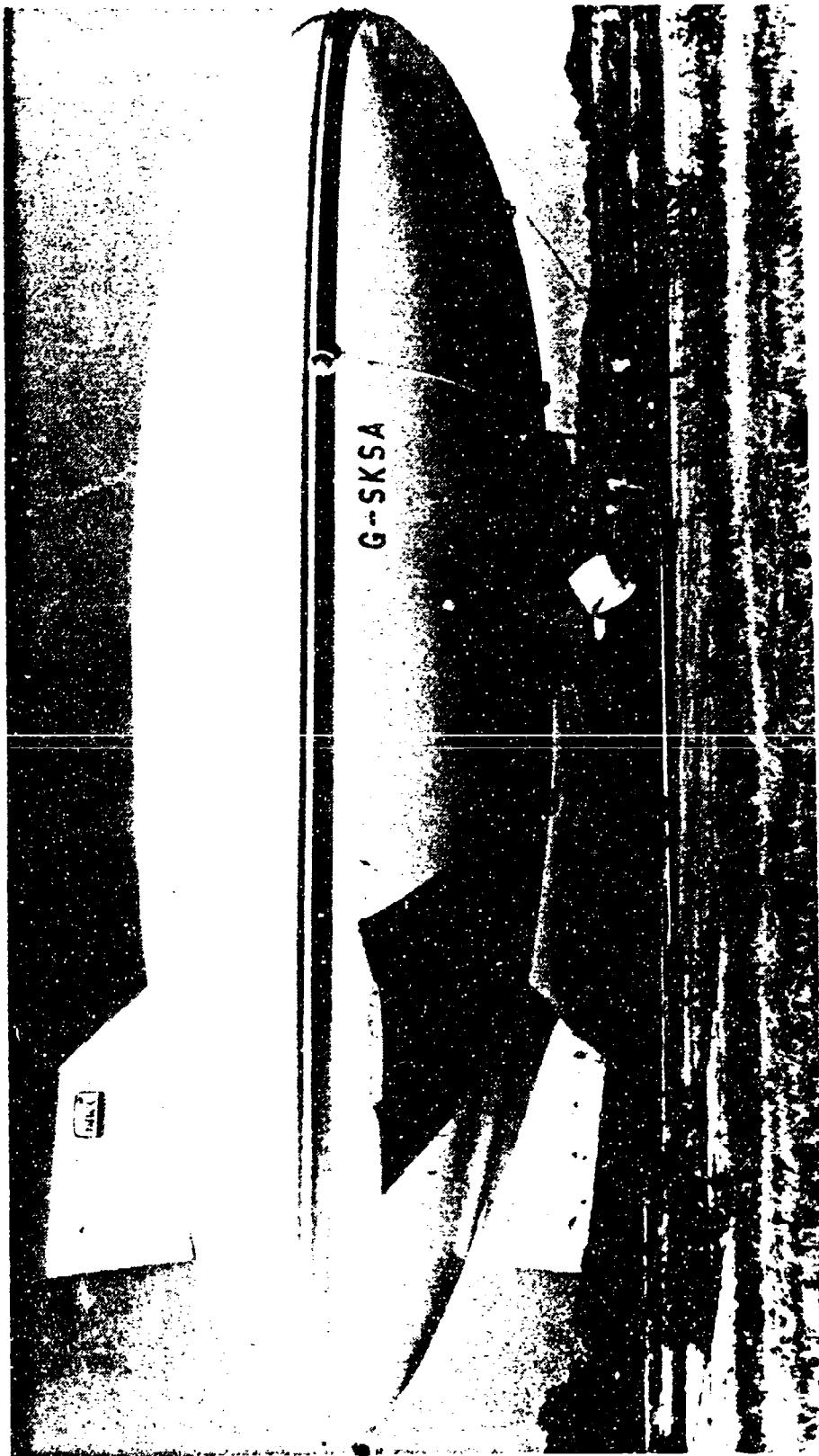
Figure 5

British Skyship 500 Undergoing
U.S. Navy Tests

Source: 21

On 5 June 1987, the Naval Air Systems Command awarded a $168.9 million contract to Westinghouse and Airship Industries for an operational development model airship. The design was based on Airship Industries' proposed Sentinel 5000 airship. The airship will be the largest nonrigid ever constructed, nearly 425 feet long and 2.4 million cubic feet in volume (69:102-03).

CHAPTER 2

Strategic Mobility

Sir Winston Churchill (19:279) once wrote that "victory is the beautiful, bright-coloured flower. Transport is the stem without which it could never have blossomed." The requirement is clear; to win a war or to stabilize a situation before a conflict breaks out, troops and supplies must be transported to the region of conflict. The ability to get there is not the only important criteria. "Time is as critical a factor in war as any" and "airlift yields time..." (29:5).

Strategic Mobility Managers

Before describing problems of strategic mobility, it is helpful to understand the agencies involved and their areas of responsibility. The Defense Transportation System (DTS) "encompasses all modes of transportation (air, sea, and land) plus the mechanisms necessary to insure timely movement of our forces. The defense transportation system is composed of three Transportation Operating Agencies (TOAs): the Military Airlift Command (MAC), the Military Sealift Command (MSC), and the Military Traffic Management Command (MTMC) (11:41-3)."

The U.S. Air Force Military Airlift Command (MAC) is responsible for all Department of Defense airlift requirements. It has about seventy C-5A (see Figure 6) and 260 C-141B (see Figure 7) strategic cargo aircraft. During a national mobilization, the Civil Reserve Air Fleet (CRAF) can be activated to augment MAC within forty-eight hours.

19
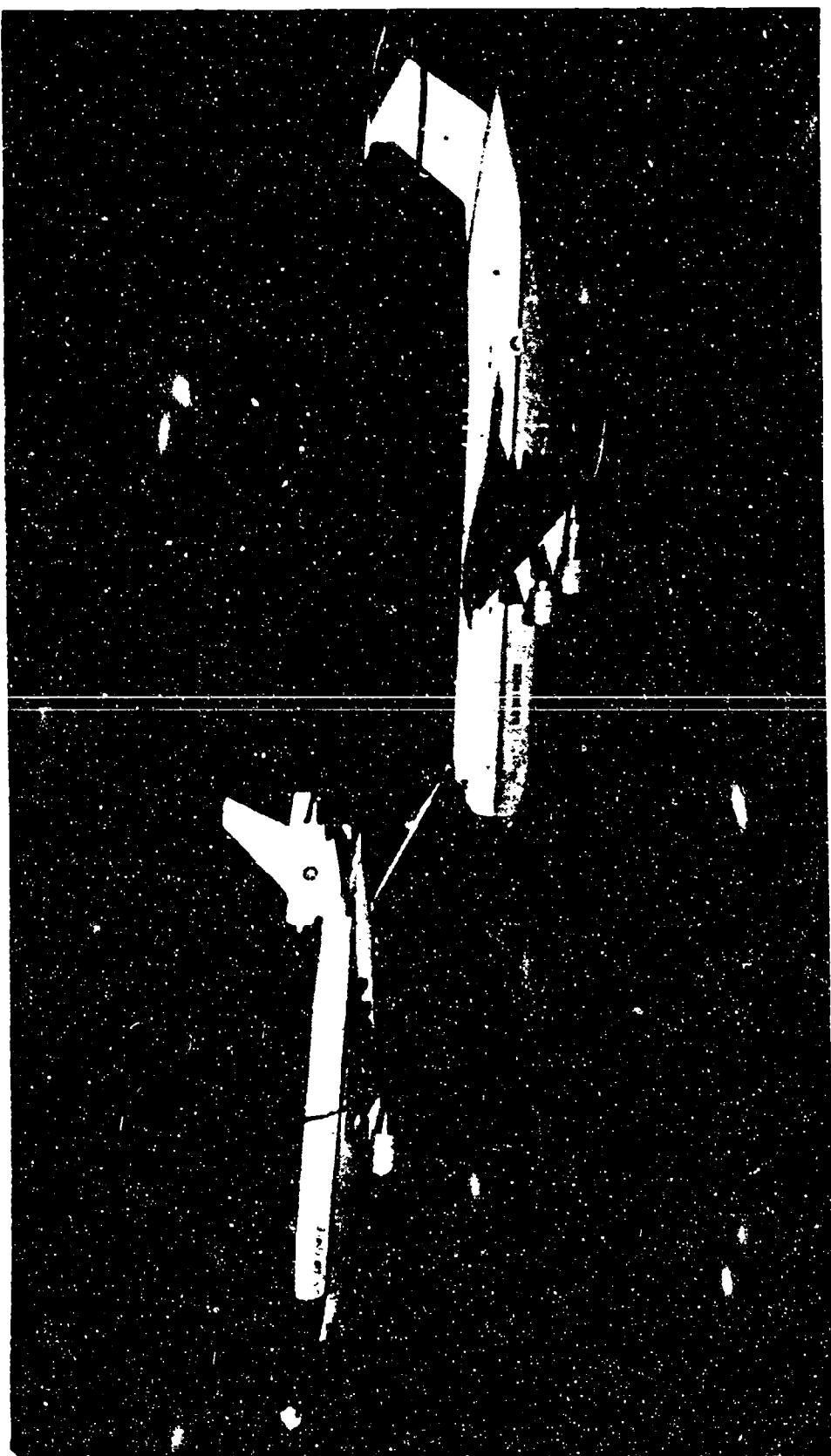
Figure 6

Aerial Refueling of a C-5 Airlifter
by a KC-10 Tanker

Source: 21
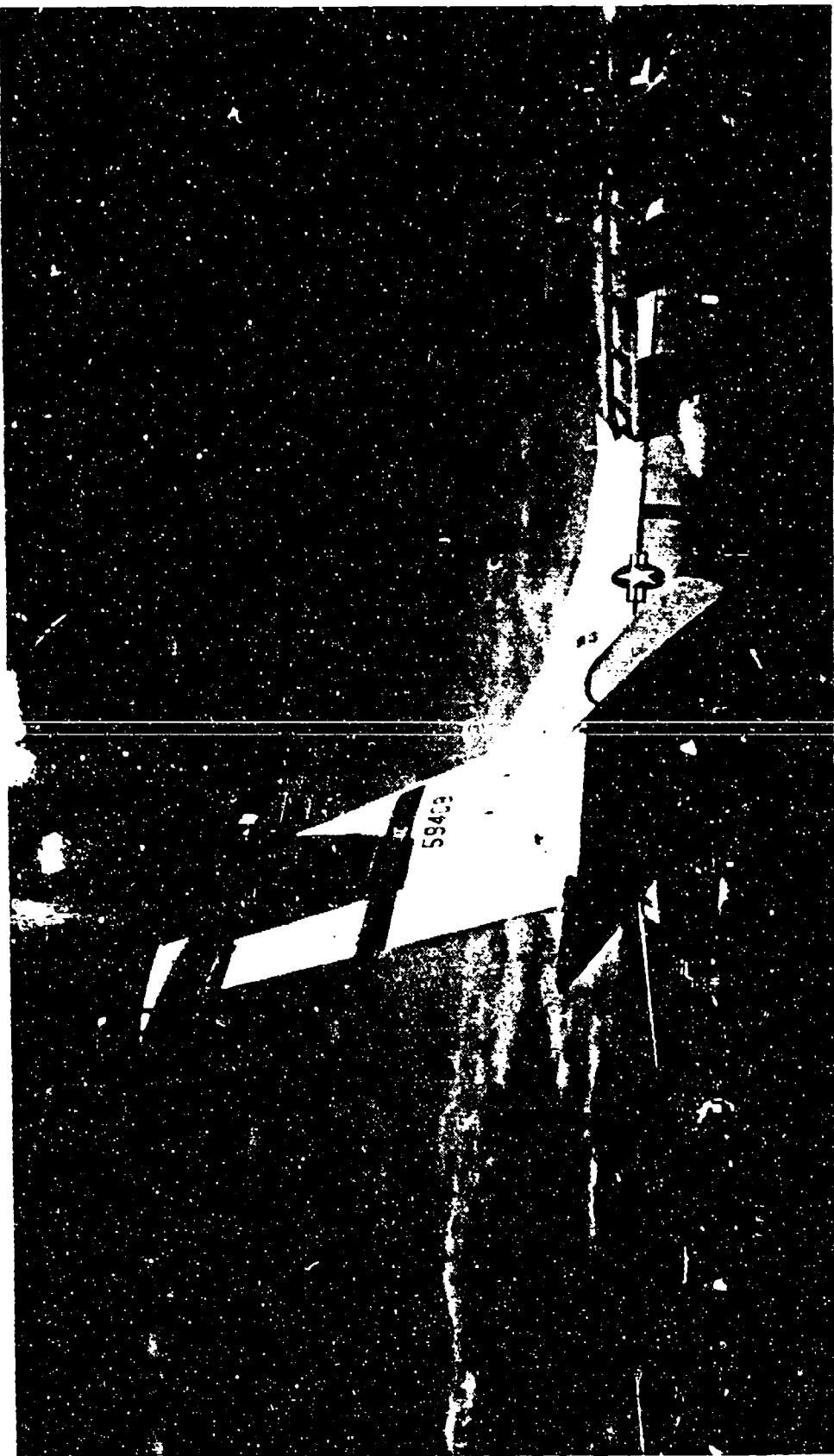
Figure 7

Two and a Half Ton Truck with Trailer Being
Unloaded from a C-141 Airlifter

Source: 21

The CRAF program is an arrangement in which certain carriers agree to provide their aircraft and people to support the airlift mission in exchange for peacetime contracts (73:61). As of February 1983, CRAF had about 330 long-range passenger and cargo aircraft (76:2).

The principal elements of sealift are just over sixty ships (see Figure 8) of the U.S. Navy Military Sealift Command. They can be augmented with almost 300 ships of the National Defense Reserve Fleet, although about 100 of these are WWII ships and need up to forty-five days to be taken out of storage and made ready. Almost 250 privately owned American cargo ships of the U.S. Merchant Marine are available to support sealift under the Sealift Readiness Program, a maritime equivalent of the CRAF program. During a NATO mobilization, almost 600 foreign ships can support U.S. deployments to Europe; the Republic of Korea has a similar agreement with the U.S. in the event of a mobilization in Korea (11:41-4; 58:4-5; 74:98,101).

The U.S. Army agency involved in strategic mobility is the Military Traffic Management Command (MTMC). Although it has no assets, the MTMC is responsible for coordinating and allocating commercial transportation in the continental U.S. (CONUS). This includes rail, truck, and air service. The difficulty is to get equipment and supplies from depots to airports or seaports using the limited commercial trucking industry and the deteriorating rail system. Currently there are only about three thousand flatbed trailers capable of carrying the heavy, wide military loads (11:41-5).
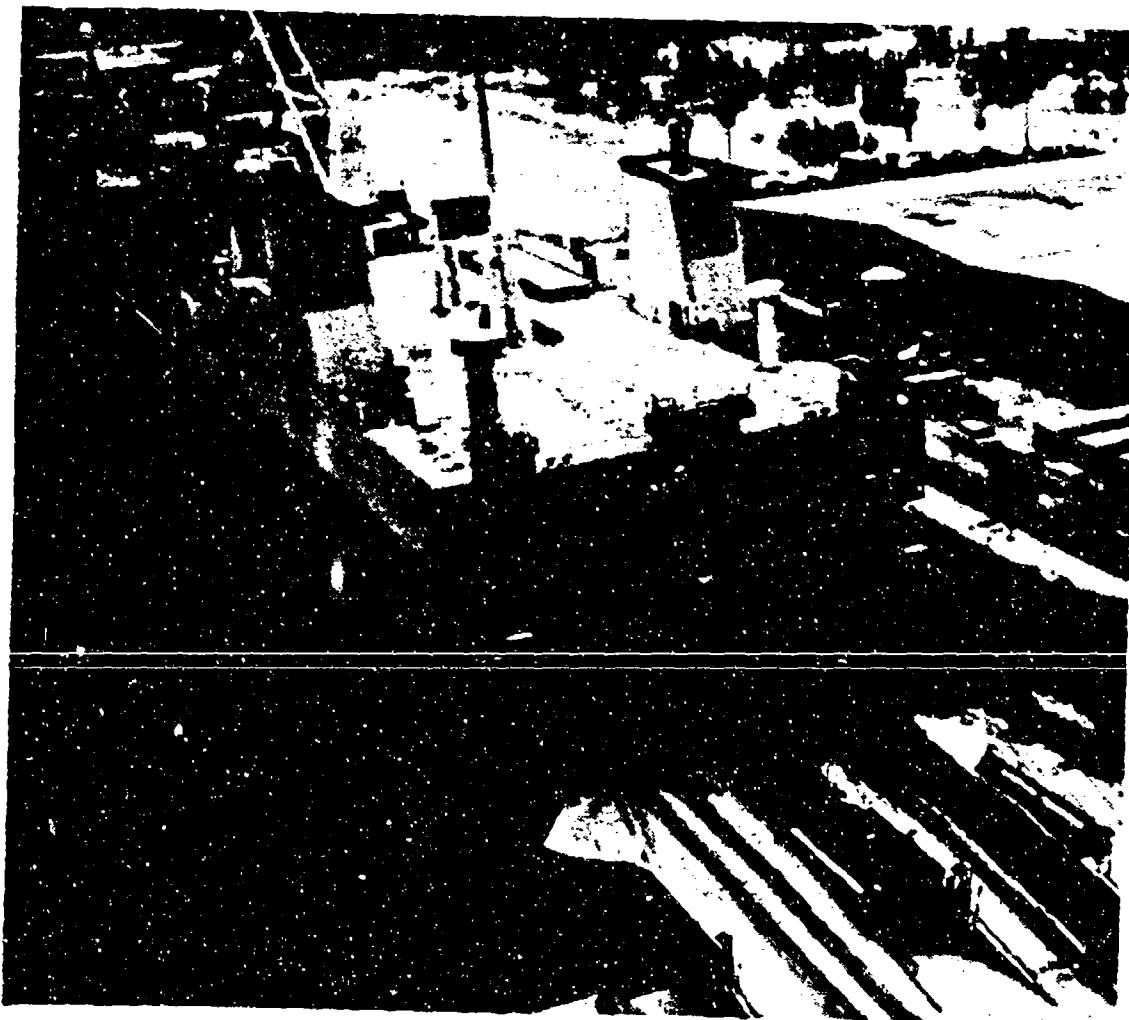
Figure 8

Roll On/Roll Off Cargo Ship Unloading Military
Vehicles from Stern Ramps

Source: 21

Strategic Mobility Experience

Experience serves to illustrate some of the major difficulties confronting U.S. strategic mobility forces. When Egypt and Syria attacked Israel in October 1973, the U.S. intervened to prevent the defeat of Israel. The first few days of the war took an excessive toll on Israeli equipment and supplies. The U.S. came to the aid of Israel by sending plane-loads of replacement material. During the thirty-three day resupply effort, the U.S. Air Force's Military Airlift Command delivered more than 22,000 tons of equipment and supplies in 145 C-5 and 421 C-141 missions (32:48). According to former Secretary of Defense, James Schlesinger,

> Our experience in resupplying Israel during the October War, for example, indicates that airlift is indispensible for the rapid transport of a limited tonnage of critical items, but sealift must be used to haul the bulk of large, heavy equipment (32:5).

Each of the C-5 missions averaged seventy-four tons of cargo and each of the C-141 missions averaged 27.5 tons. The long distances and heavy loads required the aircraft to make a refueling stop. Political issues prevented the aircraft from using European-based U.S. tanker aircraft for aerial refueling and from using any intermediate refueling stops other than Lajes Air Base in the Azores. Without this refueling stop, the required fuel load for a nonstop flight would have limited the C-5s to only 33.5 tons of cargo per mission, and the C-141s could not have carried any appreciable cargo load (32:48-49).

The Israeli resupply effort exposed five major problems encountered in strategic mobility: distance, energy requirements, cargo

size, vehicle speed, and facilities. When an aircraft is loaded with a typical payload, it cannot carry sufficient fuel to reach worldwide destinations without landing to refuel or in-flight refueling (see Figure 6).

Politics may prevent the use of U.S. bases overseas for refueling stops or the use of such bases to launch tanker aircraft to perform inflight refueling. Airships, on the other hand, can fly slow enough to refuel from surface ships (see Figure 9), thus avoiding dependence on land bases or expensive tanker aircraft. Surface ships do not have the limited range of airplanes, but typically the distance for ships is greater than that for aircraft because the ships are constrained to seaways. Surface shipping can also feel political pressures if strategically important maritime choke points (e.g. Straits of Hormuz, Bab al Mandeb, or the Suez Canal, etc.) are closed.

Closely related to the distance problem is the energy issue. The supply line from the U.S. to Israel was 6,450 miles long (2:6-4). MAC reported that the 421 C-141 missions alone required 143 million pounds of fuel; this equates to 340,000 pounds (about 51,000 gallons) of fuel per airplane (32:48-50). One author (32:3) explained that "from the standpoint of payload and energy consumption, the airplane can hardly be considered an efficient means of transportation." Surface ships, on the other hand, are the least expensive in operating cost and energy consumption due to the efficiency of hauling large amounts of cargo (35:42).
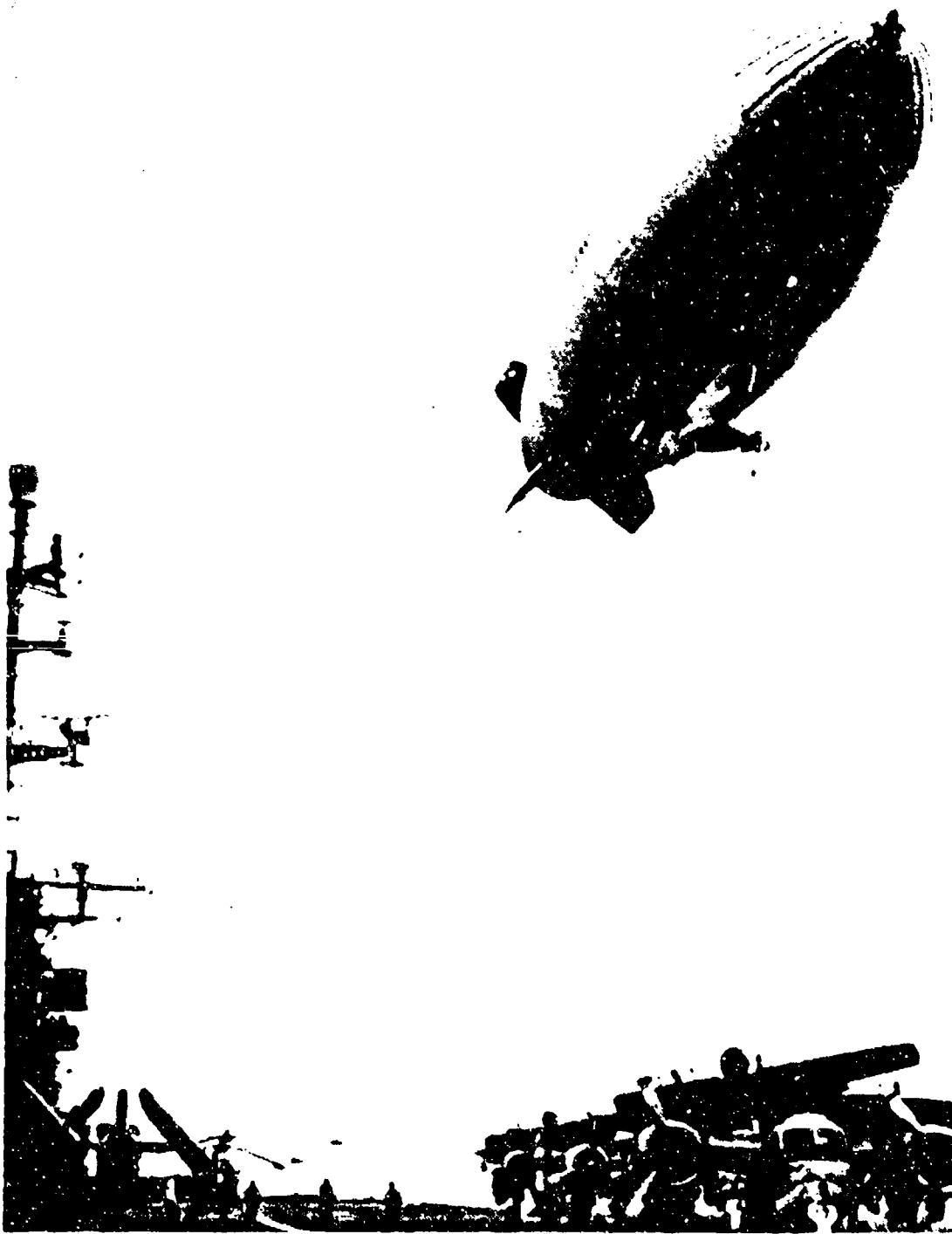
Figure 9

U.S. Navy ZPG-2 Refueling In-flight from an Aircraft Carrier

Source: 21

One of the more important pieces of equipment sent to Israel was the U.S. Main Battle Tank (MBT). Even at the present time, the only aircraft capable of lifting the MBT is the C-5 (see Figure 10). Modern military equipment does not get lighter or smaller; the U.S. Army's current MBT is about five tons heavier than the fifty-five ton MBT of the early 1970s (39:20). Certain equipment, such as the MBT, the CH-53 helicopter, and the 175 millimeter self-propelled cannon, are defined as outsized cargo meaning they are wider than normal bulk and oversize cargo (2:6-4). The size and weight of outsized cargo permits only one or two pieces to be carried at a time in the C-5. In addition to the size, the amount of cargo is also a problem (49:77); "Moving just one mechanized Army division from the U.S. to Southwest Asia, for example, would entail about 500 C-5 and 1,100 C-141 missions." Surface ships have no trouble carrying a large number of vehicles including tanks (see Figure 11). One supply ship that arrived in Israel carried the equivalent amount of material as delivered during the previous nineteen days of airlift (11:41-4). Normal mobility planning assumes that sealift will carry at least 90 percent of all overseas cargo (7:2). But where time is critical, ships are not a practical mode of transportation.

Speed is a factor only because it determines how much time is required for the mobilization. During the October War, the speed of the airlifters was apparently sufficient but this was not true for the surface ships. It is ironic to note (29:15) that "the war ended before the first sealift supplies from the United States could reach Israel."
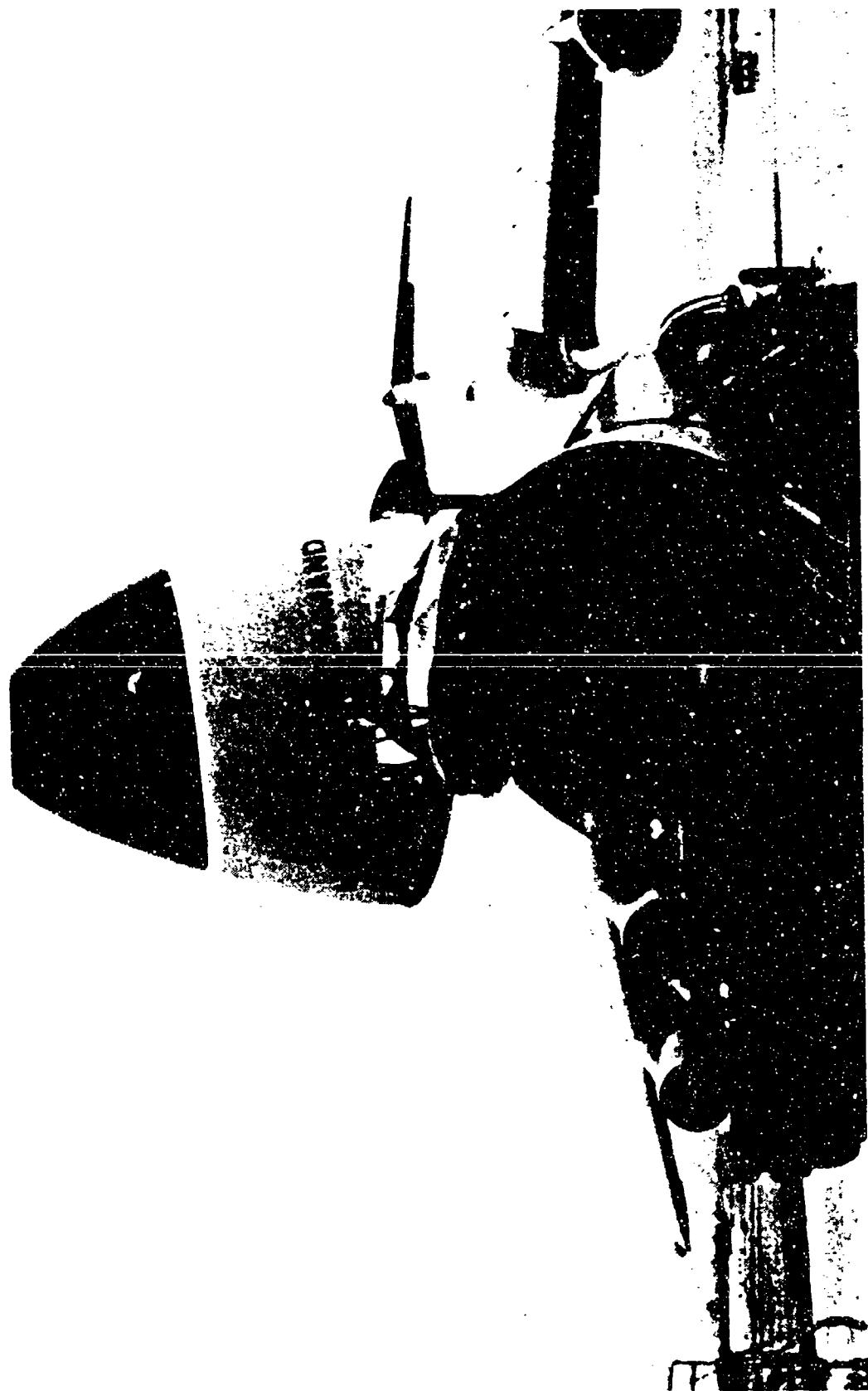
Figure 10

C-5 Unloading Outsized M-1 Tank
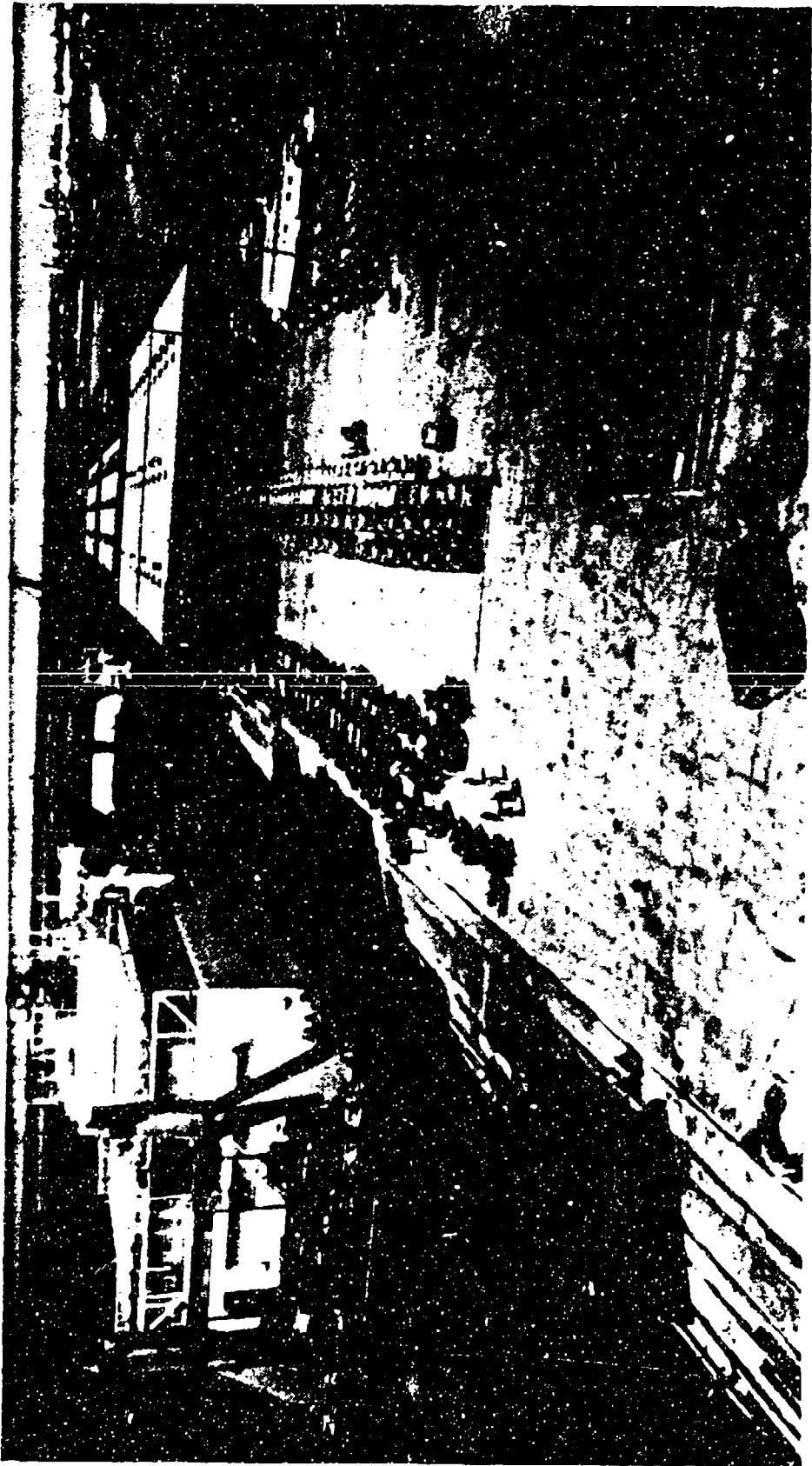
Source: 21

Figure 11

Example of Cargo Ship Capacity

Source: 21

The Military Sealift Command has eight of the fastest (thirty knots) cargo ships in the world. These ships can sail from the U.S. to Europe in about five days or to the Persian Gulf via the Suez Canal in two weeks (58:3). Neglecting loading and unloading times, these ships will still take seventeen times longer than a cargo airplane to cover equal distances, and shipping routes are usually longer than air routes.

When loading and unloading times are considered, the surface ship has a definite disadvantage when compared to aircraft for two reasons. First, the large volume of cargo that can be carried in a ship naturally requires more time to load and unload. Secondly, the cargo must be transported to one of a small number of ports (as opposed to the large number of airports where aircraft can be loaded) where the cargo must be unloaded from possibly a train or truck and then loaded onto the ship often using specialized equipment (see Figures 12 and 13). At the destination, cargo must be off-loaded and again possibly loaded on ground or air transportation for movement closer to the area of conflict. This is particularly time consuming if no ports or only poorly equipped or battle damaged ports are available. The Military Sealift Command (7:3) has eight roll on/roll off (Ro/Ro) ships (see Figures 8 and 11) and can "load or offload [sic] in one day the majority of unit equipment (tanks, artillery, wheeled vehicles, etc.) for one Army mechanized or armored division."

For the most part, military cargo aircraft need only a runway and a large forklift depending upon the type of cargo carried. The typical high wing/low cargo floor configuration of most military cargo aircraft
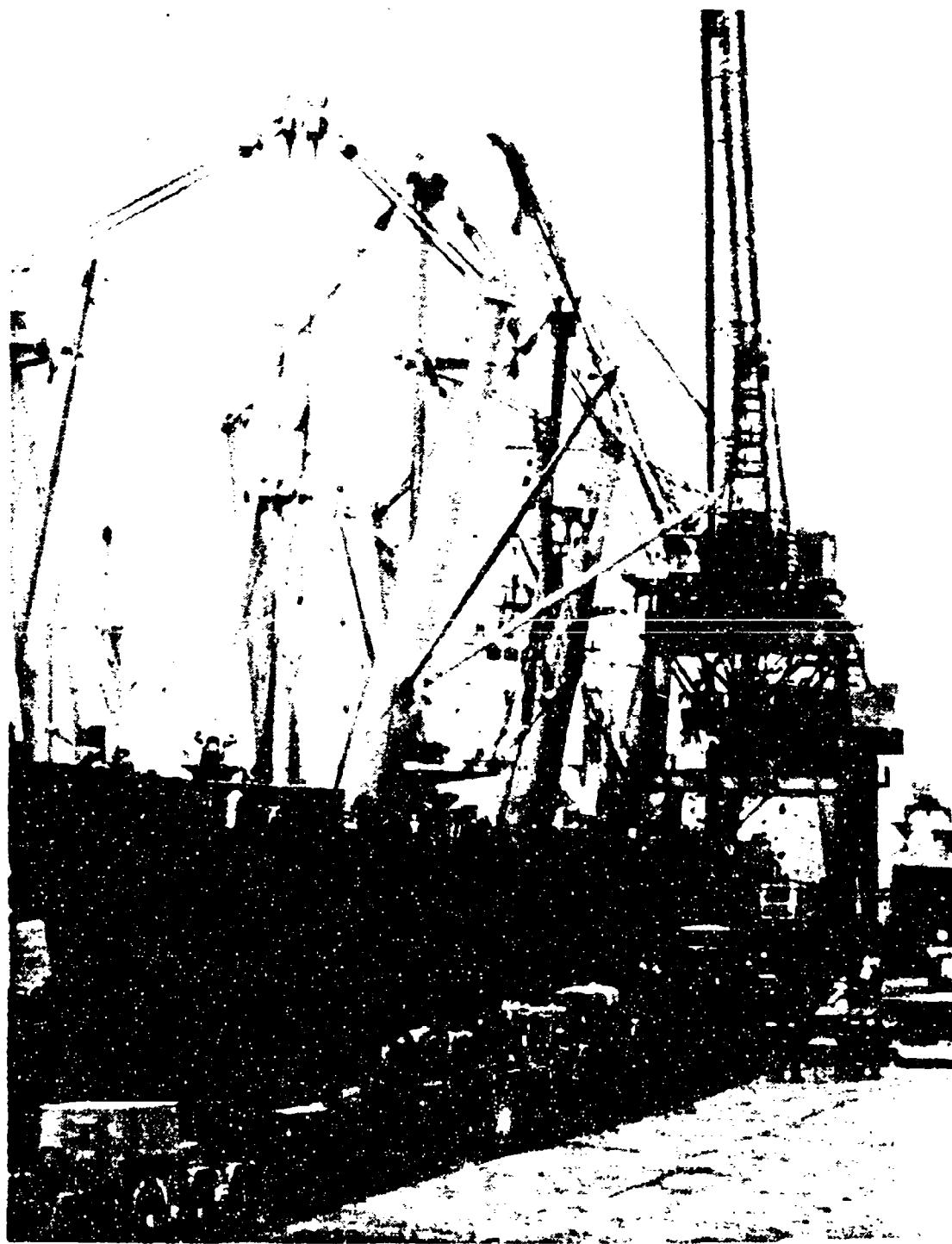
Figure 12

Specialized Port Facilities for Loading and
Unloading Cargo Ships

Source: 21
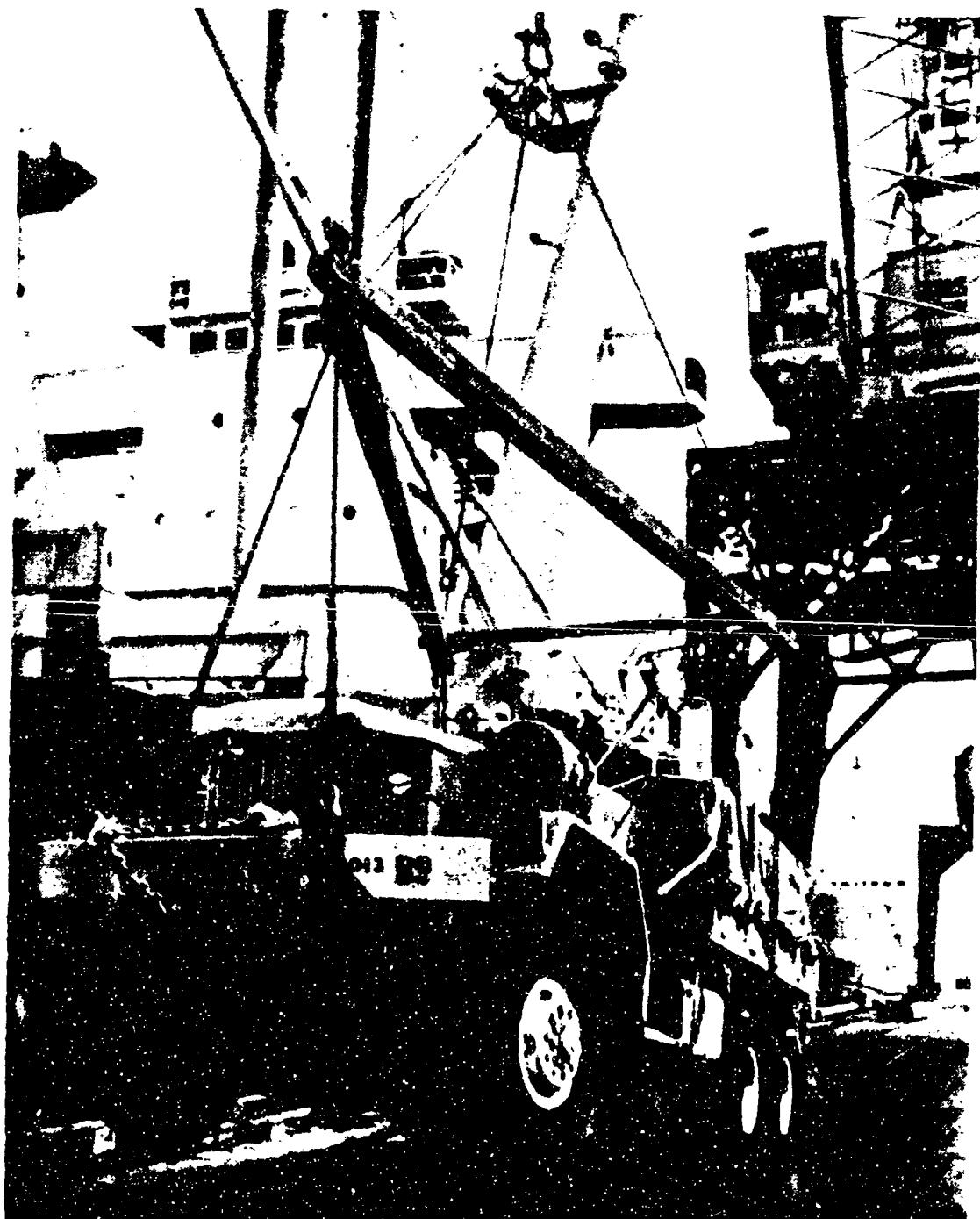
Figure 13

Five Ton Truck being Loaded Onto a Cargo
Ship by a Deck Crane

Source: 21

allows vehicles to be driven directly on and off (see Figures 7 and 10). Special cargo doors in the rear of the aircraft allow cargo to be dropped by parachute or even pushed out while flying just feet above the ground. These types of cargo extraction procedures will be discussed further in Chapter 3.

Strategic Airlift Requirements and Capabilities

As a result of recent activity in the Persian Gulf and Middle East regions, particularly the revolution in Iran and the Soviet invasion of Afghanistan, the U.S. military re-evaluated mobility requirements to support potential deployments to such regions in addition to deployments to Europe. The Congressionally Mandated Mobility Study (CMMS) analyzed the transportation requirements to support strategic mobility for four scenarios: (1) Middle East, (2) Persian Gulf, (3) North Atlantic Treaty Organization (NATO), and (4) Persian Gulf/NATO (62:48). The original CMMS requirement was to move two and a half divisions of the Rapid Deployment Force to the Middle East by air within eighteen days, at which time sealift would begin arriving (62:42).

The CMMS recommended a minimum strategic airlift capability of sixty-six million ton miles per day (MTM/D); in 1984, the MAC total airlift capability was less than half of this goal (56:45). Table 2 breaks down cargo capability by type of aircraft.

At the present time, the M-1 MBT can only be carried in the C-5. The new C-17 strategic airlifter will be able to carry the M-1, but the C-17 will not be operational before 1992 (70:1). Even with the MAC improvement programs (new aircraft, modified aircraft), there will

still be about a 17.5 MTM/D shortfall by fiscal year 1992. The C-17
will begin to close the gap at that time and is eventually expected to
close the gap completely (56:45). However, there will still be crit-
ical supplies and equipment that will have to move by slower surface
ships, and U.S. forces in other parts of the world will still need air-
lift support even though they may not be in an area of conflict. Any
proposed lighter-than-air strategic mobility vehicle should be capable
of carrying all types of cargo, including outsized and containerized.
This will allow the LTAV to supplement the C-5 and C-17, or the LTAV
can carry bulk supplies freeing the C-5 and C-17 to carry only the out-
sized, heavy cargo.

Table 2

Cargo Capability by Aircraft, 1984

Aircraft		Cargo Capability
C-5A		7.8 MTM/D
C-141B		12.2 MTM/D
CRAF Stage III		10.4 MTM/D
	Total	30.4 MTM/D
	Deficit	35.6 MTM/D

Source: 56:50

The capacity of sealift is sufficient but disadvantages must be
considered. Five cargo ships can carry the entire 101st Airborne
Division but this mode of transportation is not practical when time

constraints are imposed; at least three weeks transit time is required to travel from the U.S. to the Persian Gulf. Army and Air Force transportation experts predict it would require 1,600 C-5 and C-141 missions to move the same unit by air (11:41-1,-4,-6; 49:77). This may not be practical when fuel, refueling bases, and tanker aircraft are not available. What is needed is a vehicle with speeds much greater than surface ships, and payload capacities and ranges greater than current cargo airplanes. A modern airship may be the answer.

CHAPTER 3

Technical Problems and Vulnerabilities

This chapter will investigate natural and man-made hazards and vulnerabilities that might impose restrictions on the use of lighter-than-air vehicles for strategic mobility. In 1936, just before the end of the age of rigid airships, Arnstein and Klemperer of the Goodyear Zeppelin Company listed (6:129-131) ten outstanding problems facing airship designers at that time. The ten problems can be grouped in five broad categories: buoyancy, weather, automation, aerodynamics, and propulsion. Other areas, such as maintenance and construction materials, were not considered problems during the 1930s but should be reviewed due to the advances in technology since then. Although not addressed by Arnstein and Klemperer, vulnerability is a problem that must be examined for military airships. These problems will be analyzed and solutions using current technology will be proposed.

Buoyancy Control

Lifting Gases

The most efficient gases for lighter-than-air vehicles are hydrogen and helium. Hydrogen has the greatest lift potential; 1,000 cubic feet of hydrogen can lift a seventy-one pound load at sea level (22:23-24). The major obstacle to hydrogen's widespread use in a modern LTAV is its flammability. Another problem is its effect on metals which become embrittled when exposed to hydrogen. Up through the Hindenburg

36

Era, hydrogen was the most widely used lifting gas. As concerns about safety were raised, helium, when available, replaced hydrogen.

Helium is an inert rare gas providing almost ninety-three percent of hydrogen's lift capability; 1,000 cubic feet of helium can lift sixty-six pounds at sea level (22:23-24). This study accepts the seven percent less lift provided by helium for the sake of safety particularly since the military airship may be exposed to combat. The nearest competitors to helium and hydrogen in terms of lift capability are ammonia and methane with lift capabilities of thirty-one and thirty-four pounds per 1,000 cubic feet respectively (32:13); both of these gases require twice the volume of hydrogen or helium filled airships to lift the same weight. This study will consider only helium as a practical lifting gas.

In the early days of airships, the United States was thought to be the world's only source of helium, and since some countries did not have access to helium, their hydrogen-filled airships sometimes ended in fiery disasters. Since then, helium has been discovered in the gas fields of the North Sea, in the Sahara, in the Netherlands, in Eastern Europe, and in the Soviet Union (64:16).

In 1984, Grade A (99.995 percent pure or better) helium sales by American private industry and the U.S. Government amounted to 1,637 million cubic feet of which almost 464 million cubic feet went into storage and 392 million cubic feet were exported (40:461-462). Other countries produced 150 million cubic feet of helium in 1984, with Poland producing the majority (40:467). The selling price for gaseous

helium has remained fairly constant over the last twenty years, averaging around ^{35} per thousand cubic feet (36:577; 40:461) as compared to slightly over $1 to produce the same amount of hydrogen (17:339). Helium is found in natural gas in various proportions; natural gas fields in the U.S. have the highest proportion of helium, 0.3 percent. The primary method for producing helium from natural gas is by the cryogenic extraction process (40:461). Known helium resources in the U.S. as of January 1984 totaled 484 billion cubic feet, or enough to fill the largest airship ever built over sixty-seven thousand times. It is interesting to note that seven million cubic feet of helium, or enough to fill the largest airship ever built, is used for purging systems on the space shuttle prior to each flight. The major uses of helium in the U.S. are in cryogenics, and for pressurizing, purging, and welding. These uses account for about 70 percent of the domestic consumption of helium. Just over 3.5 percent of the helium is employed as a lifting gas (40:464-466). The conclusion of the Apollo space program during the late 1960s and early 1970s led to a sharp decline in helium consumption; otherwise, helium use has been growing at an average annual rate of almost 5 percent since 1960 (see Figure 14) (36:580; 40:463).

Effects of Altitude

Altitude has a significant effect on the lifting gas. As altitude increases, air density, pressure, and temperature decrease (within the troposphere). As the airship ascends, the displaced air weighs less. This decrease in air density causes the useful lift of the vehicle to

Helium Production in the U.S.
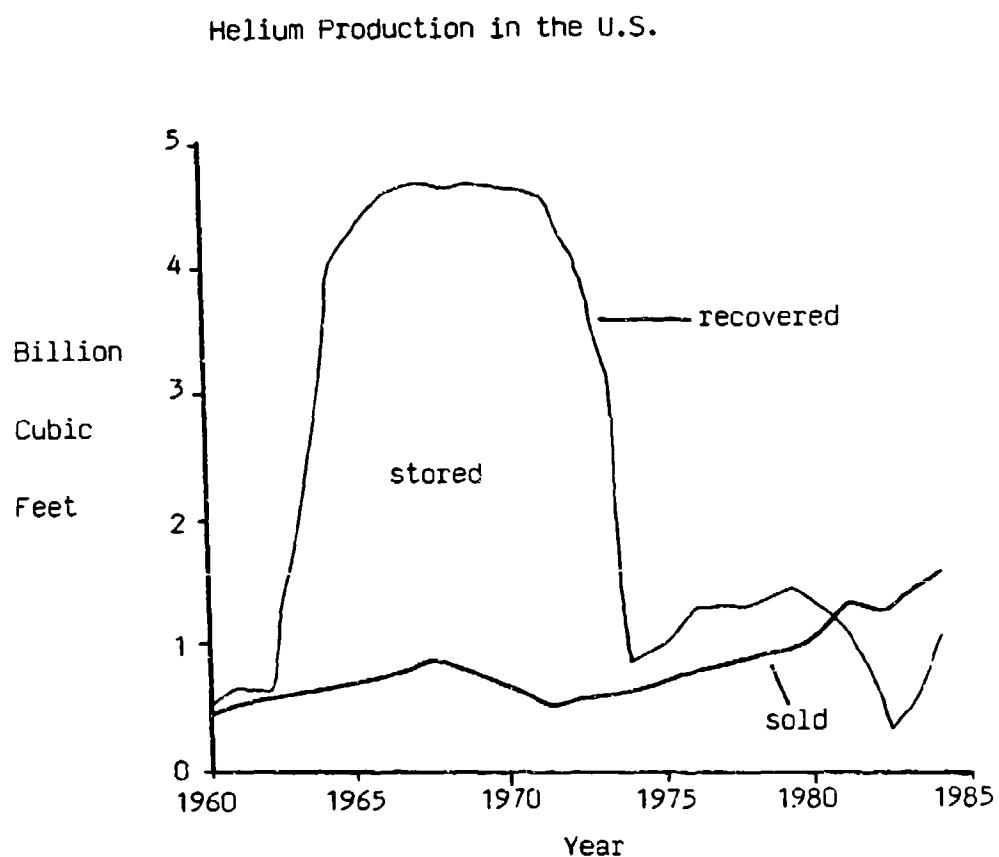
Figure 14

Helium Production in the U.S.

decrease. This limitation in lift results in an equilibrium at some altitude known as the static ceiling. To operate at a higher altitude requires the gross weight of the airship to be reduced or the amount of lifting gas to be increased (32:14; 81:25). For an airship flying about 5,000 feet above the ground, the effects of pressure and temperature are negligible. These atmospheric effects can be seen in Equation 1 (52:28-31):

$$R = U[d_a(p_a/p_g)(T_g/T_a)-d_g]-Q_s-Q_L \qquad \text{Equation 1}$$

where

R = resultant lift force (lb)
U = total volume (ft^3) at standard atmosphere
d_a = density of air at standard atmosphere (slugs/ft^3)
d_g = density of lifting gas at standard atmosphere (slugs/ft^3)
p_a = air pressure at altitude (psi)
p_g = lifting gas pressure at altitude (psi)
T_a = air temperature at altitude ($^\circ$F)
T_g = lifting gas temperature at altitude ($^\circ$F)
Q_s = weight of airship structure (lb)
Q_L = weight of fuel, passengers, cargo, ballast, etc. (lb)

Burgess provided an example (16:39) of altitude effects on density and ultimately on the lift potential of an LTAV. Table 3 illustrates how decreasing air density affects the LTAV's gross lift (maximum weight of the LTAV, fuel, and payload that can be lifted).

Another effect illustrated in Equation 1 is caused by the fact that atmospheric pressure decreases with increasing altitude which causes the lifting gas to expand in the gas cells. When the pressure in the gas cells increases, the pressure ratio term becomes smaller. The pressure ceiling is the altitude at which the gas cells are full and cannot expand any further without rupturing. This is the maximum operating altitude for the given configuration. To operate higher than

the pressure ceiling requires that gas be vented from the cells. If gas is vented, lift is reduced, thereby requiring a corresponding decrease in gross weight if the airship is to maintain the higher altitude (32:13; 81:25). Venting of helium lifting gas may be expensive and may prove difficult to obtain in certain areas of the world. On the other hand, hydrogen is very inexpensive and can easily be procured. In emergency situations, hydrogen may be used to replace lost or vented helium without any adverse performance effects on the airship, but the risk of explosion must be considered.

Table 3

Altitude Effects on Air Density and Lift Potential

altitude (ft)	air density at altitude / air density at sea level	gross lift (lb)	LTAV weight (lb)	payload potential (lb)
0 (sea level)	1.0	125,000	95,000	30,000
6,000	.837	104,600	95,000	9,600

Source: 16:39

In addition, Equation 1 shows that lift is a function of temperature. On a standard day, air temperature decreases with altitude. The lifting gas temperature can logically be assumed to follow this trend closely, but the temperature ratio term is affected by more than just altitude. The inside of the airship usually is heated by solar radiation, similar to the greenhouse effect. This solar heating can

increase the temperature of the lifting gas which increases the

temperature ratio in the equation and results in greater lift. Solar

heating may warm the airship between ten and thirty-five degrees

Fahrenheit above the outside temperature resulting in surplus lift of

ten tons for a large ship like the Macon or Graf Zeppelin. The reverse

situation may also cause undesirable effects. Temperature lag, adia-

batic cooling, evaporation of moisture, and radiation from the ship may

result in a temperature as much as ten degrees Fahrenheit below the

outside air temperature resulting in loss of lift (6:54).

Altitude Control

The preceding section described how variations with altitude,

primarily air density, pressure, and temperature, require that an air-

ship constantly be controlled in order to maintain a desired altitude.

In addition to atmospheric effects, equilibrium can be disrupted by a

leak in the gas cells, by the added weight of precipitation, or by

taking on fuel in flight. The most common problem affecting equilib-

rium is loss of weight due to the consumption of fuel (6:55). If the

atmospheric conditions are taken into account, an airship would

gradually rise as its weight decreased due to the burning of fuel. As

the airship ascended, it would encounter new atmospheric conditions

(density, pressure, and temperature) which would again have to be taken

into account. If the gas cells were already stretched to their limits,

then gas would have to be vented or the cells might rupture.

Seven methods of altitude control appear practical and should be

analyzed: venting of lifting gas, scooping up water, recovering water

from engine exhaust, separate helium and hydrogen gas cells, gas temperature control, airship pitch control, and vectored thrust. The first five methods actually change the buoyancy of the airship while the last two methods only redirect forces to change the altitude.

Venting of lifting gas was done primarily to prevent the gas cells from rupturing when an airship was near its pressure ceiling. Venting also aided in stopping sudden altitude increases by reducing buoyancy. When early airships used hydrogen lifting gas, venting was feasible because hydrogen was inexpensive and readily available almost worldwide. Helium is much more expensive and is not readily available throughout the world so this method is not practical in modern airships (6:55). If the airship had a gas compression and storage capability then helium could be vented from the gas cell and stored under pressure until required at a later time. Such a system appears to be too heavy to be practical, but there are indications (64:39) that the Soviets have such an automatic gas compression system on one of their airships.

Water is commonly used as ballast because it is easy to transfer and has a fairly high density. To increase buoyancy, the airship would jettison water, and to decrease buoyancy or descend, the airship would take on water. According to some experts, scooping up water is the first choice for adding ballast because it is the lowest cost and lowest complexity of any buoyancy control system (17:123). This method does not seem the best for an airship that may have to travel to areas where there may be little water. Also, using saltwater as ballast may result in corrosion of the recovery and storage system. Scooping up

water would require the airship to slow down and descend; this would increase the flight time and the climb back up to cruising altitude would increase fuel consumption. This method does not appear practical for a strategic mobility airship.

The U.S. Navy developed a successful method for recovering water from engine exhaust gases (6:56). This third method appears practical and effective for buoyancy control in modern airships. Studies by both the U.S. Naval Research Laboratory (20:4) and by the Martin Marietta Corporation (43:50-51,74,102) indicate that approximately 1.3 pounds of water can be recovered from engine exhaust for each pound of ordinary aviation fuel burned. This can be illustrated in a chemical reaction using octane (C_8H_{18}) as the fuel.

$$C_8H_{18} + 12\ 1/2\ O_2 + 47\ N_2 \longrightarrow 8\ CO_2 + 9\ H_2O + 47\ N_2$$

"Here the theoretical, stoichiometric, or chemically correct amount of air has been used; that is, the exact amount of air for conversion of the fuel into completely oxidized products (54:90)." The oxygen (O), nitrogen (N), and carbon dioxide (CO_2) are present as gases. The water (H_2O) is present as a vapor which can be condensed. Table 4 shows that the weight of the water that can be recovered is greater than the weight of the fuel burned. In the ideal reaction, about 1.4 pounds of water can be recovered for each pound of fuel burned.

Martin Marietta estimated that a 4,000 pound water recovery system (including pumps, valves, and lines) would be sufficient for a nine million cubic foot airship. The proposal calls for the water to be stored in empty fuel tanks to reduce weight associated with a water

recovery system. For an airship with a specific fuel consumption of 0.5 pounds per hour per horsepower and a power output of 20,000 horse-power, approximately 6.5 tons of water can be recovered every hour.

Table 4

Weight of Water Recovered from Exhaust Gas

molecule	molecular weight (lb_m/mole)	number of molecules in reaction	resultant molecular weight (lb_m)
octane (fuel)	114.140	1	114.140
water (by-product)	18.016	9	162.144

Source: 54:721

The fourth potential solution to altitude control was described by Arnstein and Klemperer (6:56) of the former Goodyear Zeppelin Company; helium would be the primary lifting gas and would be complemented with special hydrogen gas cells. The hydrogen would provide lift and be used for buoyancy control by venting. Bloetscher (12:123), also of Goodyear, suggested burning some of the hydrogen lifting gas as fuel and recovering the sole by-product, water, for ballast. Both of these methods, while appearing practical and even recommended in an emergency situation, would sacrifice the inherent safety of the helium-only design. Therefore, neither of these methods are considered practical for the strategic mobility airship.

Another method to increase lift was introduced by the temperature ratio in Equation 1. Heating of the lifting gas by engine exhaust can increase the temperature of the gas which results in increased lift, similar to hot air balloons. This method appears feasible although no system has been used in rigid airships before and there is limited knowledge available about such a system. Some experts believe heating is probably of limited effectiveness (6:55). On the contrary, a noted Soviet airship expert, Tsiolkovskiy, devoted an entire chapter (52:354-376) to heating of lifting gases for increased lift. A Naval Research Laboratory report proposed filling gas cells to 85 percent capacity and using heat to obtain full lift (20:14).

The following example illustrates the advantage of increasing the temperature of the lifting gas. If the lifting gas volume remains constant, temperature and pressure are related as shown in Equation 2 (47:404).

$$P_1/(T_1 - c) = P_2/(T_2 - c) \hspace{3cm} \text{Equation 2}$$

where

P_1 = initial pressure (psi)
T_1 = initial temperature ($^{\circ}$F)
c = constant, -460°F
P_2 = final pressure (psi)
T_2 = final temperature ($^{\circ}$F)

Without superheating, the temperature approximates the air temperature, or sixty degrees on a standard day. Also, the gas pressure is assumed to be the same as the ambient air pressure, or 14.7 pounds per square inch (psi). If the final pressure is assumed to be 15.0 psi with superheating, then the temperature is calculated to be almost 71 $^{\circ}$F.

Table 5 presents a breakdown of terms in Equation 1 for the super-
heating case and the non-superheating case. By applying the numbers
from Table 5 to Equation 1, a definite advantage can be seen for using
superheating; however, this example does not consider the added weight
and complexity of related equipment. Superheating the gas from a
ground-based energy source just before takeoff appears practical since
the equipment would not be carried on the LTAV thus negating any weight
concerns (6:54-55).

Table 5

Comparison of Lift for Different
Lifting Gas Temperatures

		Without Superheating	With Superheating
Density (lb/ft^3):	air	0.0763	0.0763
	helium	0.0640	0.0640
Temperature ($^\circ$F):	air	60	60
	helium	60	71
Pressure (psi):	air	14.7	14.7
	helium	14.7	15.0
Total Volume (ft^3) (assumed)		10,000,000	10,000,000
Weight of Structures (lb) (assumed)		50,000	50,000
Weight of Fuel, Cargo, etc. (lb) (assumed)		57,740	57,740
Resultant Lift Force (lb)		15,260	132,253

The sixth effective method of controlling altitude is through the use of pitch control. Although airships rely on aerostatic forces for lift, significant lift can be achieved by aerodynamic forces acting on the large hull during forward motion. These aerodynamic forces create lift which can be controlled by changing the pitch of the airship. With a nose down pitch, or negative angle of attack, the aerodynamic lift can be reduced or made negative thus allowing the airship to descend; the opposite is true for a nose up pitch, or positive angle of attack. Aerodynamic lift can be as much as 15 percent of the aerostatic lift on a conventional rigid airship (64:17). This method seems practical for short durations, but aerodynamic lift causes an increase in drag and in the required power if constant airspeed is to be maintained (6:88; 32:14-15).

The last potential method to control altitude is by using vectored thrust. Vectored thrust is a means of using engine thrust to augment the lift resulting from buoyancy. This is usually obtained by tilting the propellers such that the thrust vector is parallel to the desired direction of travel. It is primarily for control during vertical takeoff and landing, and has been used on early airships as well as on current airships. It appears feasible that engines can provide vectored thrust during cruise operations to augment flight control surfaces such as elevators in maintaining altitude or pitch. The center of lift can be shifted fore or aft by vectoring the thrust from some or all of the engines provided the engines are significantly spaced apart along the airship's longitudinal (nose to tail) axis.

Computer Automation and Electronics

Control Systems

Controlling the amount of lift is not the only concern of buoyancy management. As with all rigid bodies, the airship will be subject to bending when external forces, such as gusts, act upon it. Controlling the location of the center of lift (typically about half way between the nose and tail) is important to prevent overstressing, or exceeding the design loads of the internal airship structure. An improperly controlled center of lift can also cause part of a low flying airship to strike the ground. The trim could be upset intentionally by jettisoning loads or ballast, or accidently by tearing of gas cells. In early airships, the crew had to react quickly by jettisoning an appropriate amount of ballast or releasing some gas (6:60).

> In the large airships of the past, direct mechanical connections were used from the helmsmen's stations to the control surfaces. Marine-style engine telegraphs were used from the control car to the engine cars. Both the flight controls and the engine controls are prime candidates for a fly-by-wire system. Because of the large dimensions of the conceptual lighter than air (LTA) vehicles, both weight savings and improved control can be achieved by replacing mechanical cables and tensioning devices with light-weight instantly responsive signal wires (43:11).

The challenge of an adequate control system can be met using current technology flight control systems which employ microcomputers and electromechanical devices. Digital engine control systems can replace heavier, costlier, and less reliable hydromechanical systems (66:28). In addition, electrically actuated systems do not have the flammability associated with hydraulic systems (66:97). "The lack of control over

gust-induced motions. . ." has historically been a problem for airships especially during ground operations (72:426). Digital control technology developed during the Apollo lunar lander and Viking Martian lander programs has the potential for solving the thrust/gust control problem that has plagued airships since their beginning (43:11).

The new Sentinel 5000 being built by Airship Industries for the U.S. Navy (69:103) "will have full autostabilisation and autopilot provided by a GEC Avionics flight control system using fly-by-light (computer controlled, optically signalled) control actuation." In addition, it will have a "hands-off autopilot control for cruising, hovering, and mooring, and automatic speed control." (69:103)

Fly-by-wire or fly-by-light (fiber optic) systems combined with a computer "could assess the effects of battle damage and reconfigure the aircraft to fly as efficiently as possible within seconds of a hit, and without any intervention by the pilot" (66:97). The Air Force's Aeronautical Systems Division is currently studying the use of computers to determine how to modify an aircraft's control system to overcome the loss of flight control surfaces such as ailerons, elevators, and rudders. Reconfiguration on an airship could involve sensors to detect a sudden loss of gas pressure or an uncommanded moment and react properly. The automatic reaction could be a release of ballast or a change in the thrust vector by one or more of the engines to maintain a safe center of lift. After the computer system corrected a problem, the flight crew members would then have time to analyze the situation and take more long-term corrective actions.

Avionics

Modern avionics provide much more information to the crew members than was ever considered possible in early airships. Besides the advances in automation, some of the most important advances have been in navigation and communication systems. Satellite communications systems allow an aerospace vehicle to communicate with almost any location in the world; this allows access to global weather reports. Weather radars can be used on LTAVs to find safe flight paths through storms. Weather information can be fed into an autopilot to take the vehicle along the best flight path to take advantage of tail winds and avoid storms. The new Global Positioning System, when fully operational, will allow aircraft positions to be determined more accurately than ever before. Accurate knowledge of the airship's location will assist in fuel conservation by allowing direct flights, in self defense by avoiding hostile areas, and in air safety by avoiding congested airways used by faster aircraft. Many latest generation aircraft, such as the Boeing 757, Boeing 767, the Rockwell B-1 Bomber, and the McDonnell-Douglas F-18 Hornet, use cathode ray tube displays and digital avionics to replace less reliable mechanical avionics.

Vehicle Design

Computer technology can be employed during the design and construction phases. Computer-aided-design/computer-aided-manufacturing (CAD/CAM) has been successfully used in the development of several of the latest generation aircraft. CAD/CAM reduces manpower intensive tasks and decreases design-related costs. Design changes during

initial construction or later in the airship's life can be made much
faster using automation than with manual drafting.

Crew Training

Computer automation has been used in simulation for pilot training
for many years. Flight simulators have become so sophisticated, that
for some airplanes, the pilot can receive all advanced training in the
simulator. Simulators are used for initial training, proficiency
training, and emergency procedures training. The simulation involves
not only the routine cruise portion of the flight, but also the
landing, takeoff, and special maneuvers. Simulators for some larger
Air Force aircraft even simulate aerial refueling complete with a
visual display. The use of flight simulators for a modern airship
training program is inevitable (20:17).

Effects of Weather

When debating airship safety, the subject of weather is usually
brought up. This is primarily because most people recall a few airship
disasters of the past and often relate the cause of the airship's
demise to the slightest atmospheric disturbance. Of the twelve rigid
airships built after WWI, only one, the U.S.S. Shenandoah, was
destroyed as a direct result of severe weather. Six of the twelve were
peacefully dismantled and four of those destroyed had significant con-
tributing factors.

While performing aerobatic maneuvers, the British airship, R38,
suffered structural failure. The loss of a later British airship, the

, R101, was due to a poor design which was not discovered due to inade-
quate testing. An altimeter error on the U.S.S. Akron led to a
dangerously low altitude; a sudden downdraft from a storm slammed the
Akron into the ocean. The U.S.S. Macon had a known structural defect
due to improper maintenance which led to structural failure. The cause
of the Hindenburg disaster may never be known. Some theories are that
lightning or a static discharge ignited the hydrogen lifting gas while
others speculate that a bomb was the cause (20:9,10,12).

The physical characteristics of the atmosphere (density, pressure,
temperature) have been discussed in the previous section. This section
will present the dynamic characteristics of the atmosphere (wind, pre-
cipitation, lightning) as they affect airship operations. There are
three major areas of concern when discussing airship operations in
unfavorable weather. Two of these areas, structural integrity (proper
design and construction) and flight stability, are related to the
airship during flight. The other area is controllability during ground
operations, or maintaining a desired movement or position despite gusts
(32:28).

Flight Operations

Both the Soviets and the U.S. Navy considered the airship as an
all weather vehicle; although it can not land during bad weather, it
can ride out storms like a surface ship (31:4-5). The U.S. Navy's
airship experience (5:10) from the 1940s to the 1960s "indicates that
airships can be designed to have the same all weather performance as
other aircraft."

Violent gusts and drafts affect the structural integrity and flight stability of all aircraft. An airship caught in a sudden updraft could reach its pressure ceiling and have to vent gas to prevent further ascent and to prevent rupture of the gas cells. After venting gas and escaping the updraft, the airship might become heavy and would have to recover by jettisoning ballast. A series of up and downdrafts could exhaust ballast and reduce the gas volume to a dangerous level (32:30).

The loss of the U.S.S. Shenandoah can be directly attributed to bad weather while the loss of the Akron and Macon can only be partially attributed to weather. These U.S. airships were of the same size and general design as the German zeppelins. The German airships were subject to the same severe weather conditions as the U.S. airships but "did not suffer the fate of their American counterparts. But the Germans were also airshipmen par excellance, and their training and experience was [sic] without equal" (32:29).

Even airplanes are not immune from damage by weather; clear air turbulence has caused airplanes to drop thousands of feet, and hail from thunderstorms has damaged airplanes while flying many miles from the storms. Within the last decade, news reports have described spectacular crashes of airliners taking off with ice on the wings, and of airliners caught in a windshear (rapidly changing wind direction and speed) during takeoff or landing. Even with these sensational headlines describing airline accidents, commercial airplane travel has not been abandoned as early airship travel was. On the contrary, new

technology is employed to minimize the probability of similar accidents happening again.

Although operations in snow and ice are not desirable, the Italian airship Norge, and the German airship Graf Zeppelin, successfully participated in Arctic operations. These two demonstrations proved that airship operations in cold weather were possible (32:29). In addition to effects of very low temperatures, examples have been recorded about airship performance during periods of heavy precipitation (6:102). Dynamic lift allowed the Graf Zeppelin to carry about five tons of water from a rainstorm. The U.S.S. Akron once collected 18,000 tons of ice after it flew through a severe winter storm, but it went on to complete the remaining fifty-six hours of its mission. Current airships have no method of controlling icing other than avoiding potential icing weather. A simple, potential method of control is use of engine exhaust vented inside the hull but this presents carbon monoxide hazards.

It appears highly probable that large airships will be the target of lightning strikes. Lightning strikes on airplanes are not uncommon events. A study for the Air Force (41:1) analyzed lightning strikes on nonrigid airships to determine how to provide external conductors to minimize heat transfer to the envelope during a strike. Parts of the study are applicable to rigid airships. In general, a lightning strike on a rigid airship could be expected to have no more of an impact than what other aircraft currently face.

During periods of low cloud ceilings and reduced visibility, air-
ships have the capability to approach landing sites at very low speeds
and hover if required while preparing to land. This capability is not
possible with many airplanes (14:31), especially at austere airports
where instrument landing systems are not available.

Many technological developments have occurred in meteorology since
the era of the great airships. Today, weather radars help pilots see
and avoid most bad weather. Satellites allow pilots to see up-to-date
photographs and maps of weather developments which can indicate areas
of possible turbulence. Our current knowledge of weather, coupled with
modern equipment, can reduce severe weather encounters and provide
routes of optimum wind conditions to improve speed and fuel efficiency.

Ground Operations

Ground operations include activities such as landing, takeoff,
mooring, loading and unloading. While performing these operations,
lighter-than-air vehicles must be under continuous control to prevent
turbulence from rapidly upsetting the buoyant equilibrium or from
blowing the vehicle laterally into adjacent structures.

> The effects of atmospheric turbulence on the airship motions
> and structures are a continuing concern. Low-speed and
> mooring operations are especially difficult, since the
> reduced control power and ground clearance increase the
> vehicle's vulnerability to turbulence (71:1050).

Several studies have analyzed how modern technology can overcome
some of the problems confronting airships during ground operations.
One of the most promising solutions is not new but merely takes advan-
tage of technologies developed since the days of the great airships.

> One of the perennial problems of airships has been their
> lack of control power, especially at low speeds. Often, this
> has resulted in difficulty during ground handling and
> restricted safe operation in the presence of atmospheric dis-
> turbances. In order to alleviated this shortcoming, airship
> control by thrust vectoring was considered. . . . (50:408)

Thrust vectoring was used on several early airships as well as on most
of the newer airships. Vectored thrust is provided by propellers, or
entire engines, that tilt in the vertical plane to direct the thrust in
the upward direction for takeoff or in the downward direction for
descending.

Vectored thrust, also called tilt rotor, when coupled with revers-
ible pitch propellers, allows differential thrust that can be used for
steering or to overcome moderate gusts. If propulsive steering is suf-
ficiently effective, then the vertical stabilizers of the airship may
become obsolete. The lack of vertical stabilizers would greatly reduce
drag during cruise and most importantly, reduce the surface area most
susceptible to crosswinds on the ground. Table 6 shows how airship
control during changing winds can be better maintained using vectored
thrust. It has been shown that thrust vectoring and an additional
thruster located at the stern of an airship can permit greater maneu-
verability (50:411,413). Table 7 shows airship maneuverability at low
speeds using the rudder alone, or the rudder in conjunction with dif-
ferent configurations of thrusters. Tables 6 and 7 are derived from a
Goodyear Aerospace Corporation study. Studies have shown that the use
of a multiaxis closed loop control system can significantly reduce
vehicle dynamic motion (71:1056). Such a system would automatically
apply differential thrust as required to overcome gusts.

Table 6

Effects of Wind* on Airship Control
During Ground Operations

	Rudder, vectored thrust engines, bow thruster	Rudder, vectored thrust engines, stern thruster	Rudder, vectored thrust engines
Vehicle horizontal excursion (ft)	210	215	950
Vehicle altitude excursion (ft)	+12	+10	+40

*15 knot wind shifting by 90 degrees.
Source: 50:412

Table 7

Airship Maneuverability at Low Speed*
Using Vectored Thrust

	Rudder alone	Rudder and bow thruster	Rudder and stern thruster
Turning radius (ft)	490	100	60
Time to turn (sec)	240	45	44

*Turning speed: constant 10 knots.
Source: 50:411

The use of vectored thrust may even substitute for some of the ballast. By tilting the propeller in the proper direction, the thrust effects are similar to adding or reducing weight, with the resulting motion of the airship. For ballast equal to 6 percent of the gross

lift, as a Naval Research Laboratory report recommends (20:14), the ballast would be 60,000 pounds for an airship with a gross lift of 1,000,000 pounds. The same effect of the 60,000 pounds could be achieved by several engines vectored in the appropriate direction.

Besides ground maneuvering, vectored thrust has also increased the airship's flexibility during landing and takeoff by permitting shallow or steep flight paths as desired (50:410). The vertical takeoff and landing capability is useful during periods of low visibility when obstacles around the landing site can not be seen. High ascent angles permit avoidance of surrounding obstacles. Also, when the airship is directly over a landing site, it can begin its vertical descent to avoid surrounding obstacles. The area required is in the order of two or three times the length of the LTAV which is much smaller than the three mile radius clear zone recommended for early airships. Some experts believe that the area required to handle a few modern airships would have to be as big as a large city airport. Airships would most likely be incompatible with modern airports (32:33; 81:25).

Only about a dozen hangars are still in existence in the U.S. that could handle airships of the ten million cubic foot class. Only one is available to handle LTAVs up to fourteen million cubic feet (32:26; 81:25). Most of these structures are old and would require renovation. For larger airships, new and expensive facilities would have to be built. In any case, very large facilities will probably be required for construction of modern airships. In the past, airships were constructed in hangars, but due to the anticipated size of a new

airship, final assembly would most likely take place outside. This limits the construction site to a region dominated by good weather, most likely the southwest U.S. Construction of components could take place inside a hangar.

If an airship must be moored in the open rather than in a hangar, it should be moored at the bow with the tail left free to swing later-ally with changing wind direction. This will allow symmetric air flow and minimize pitching and rolling tendencies in fluctuating winds thus reducing the stresses on the airship (6:120). These precautions are not unique to airships. Even airplanes require tiedowns in certain weather conditions. In extreme weather, airplanes are flown to safer locations until the storm passes.

The early airships required up to sixty men during docking oper-ations (22:51). In the 1950s, the U.S. Navy had a ground handling system (see Figure 4) that allowed twelve men to dock an airship, although only 1.5 million cubic feet in volume, in winds up to fourteen knots. Once docked, the airship could ride out winds up to ninety knots (43:19-20). The system included tractors, mobile masts, and a tail support (22:50).

Goodyear has a deployment system consisting of a communications bus, a van for command center, and a forty foot tractor-trailer carry-ing a portable mooring mast (59:7). Although these mobile docking systems are more flexible than a fixed mooring mast, they still require equipment to be located at the landing site before the airship arrives. Some experts believe that ground facility requirements and operating

procedures for a modern, large airship are just a straight forward
extrapolation of data from the historic airships (20:9).

Overcoming Weather and Buoyancy Problems
While Loading and Unloading

Loading and unloading cargo is much more difficult with an airship
than with an airplane. First, there must be some type of buoyancy
control system to prevent internal cargo movement from causing a
disastrous shift in the center of gravity. Secondly, there must be
some type of control system to negate the effects of gusts. Thirdly,
there must be a cargo loading and unloading system that permits rapid
turn-around times to minimize the amount of time the LTAV is exposed to
ground hazards. Solutions to the first two problems, buoyancy control
and gust control, were proposed in a previous section of this chapter
entitled Control Systems.

Because of their inherent buoyancy, airships require a force to
hold them down to the ground during loading and unloading operations.
In the past, water was used as ballast to hold the airship down. After
all the cargo was loaded and when the airship was ready for takeoff,
the ballast was released. When the airship was ready to land, extra
ballast was taken on or lifting gas was vented. Venting of lifting gas
should be a last resort because of the expense and availability of
helium. The use of ballast is recommended but a sufficient quantity
may not be available. Vectored thrust engines provide a practical
means of holding the airship down during rapid loading and unloading
operations. Computer control systems coupled to the propulsion system

could balance moments and maintain the desired vehicle orientation during loading and unloading (14:34). At the same time, the engines could be used to negate the effects of gusts.

Internal Cargo System

Before discussing rapid cargo loading and unloading, it is necessary to define a cargo system. The cargo can be carried internally or externally in an airship. Carrying the cargo externally reduces the structural weight of the airship since the heavy cargo floor is attached only when cargo is carried (53:65). Since externally carried cargo greatly complicates vehicle control during ground operations and increases drag during flight (51:830), this study proposes use of the internal cargo configuration since it is the least complex.

The cargo loading and unloading system should not add significant extra weight to the airship at the expense of the payload. The system should allow rapid loading and unloading to reduce the ground turn-around time. It should not require unique or large amounts of ground support equipment at the deployment location where austere conditions can be expected.

A practical system is the Air Force 463L materials handling system. This system uses pallets made of aluminum covered plywood sheets, eighty-eight inches by 108 inches, to hold cargo, and a 108 inch rail system to move the pallets inside the aircraft (see Figure 15). The pallets weigh 290 pounds and require three nets totalling sixty-five pounds to hold the cargo down. Each pallet has a maximum capability of 10,000 pounds (73:62). The rail system has locks to secure the loaded

63

Figure 15

Air Force 463L Cargo System Handling Palletized Cargo

Source: 21
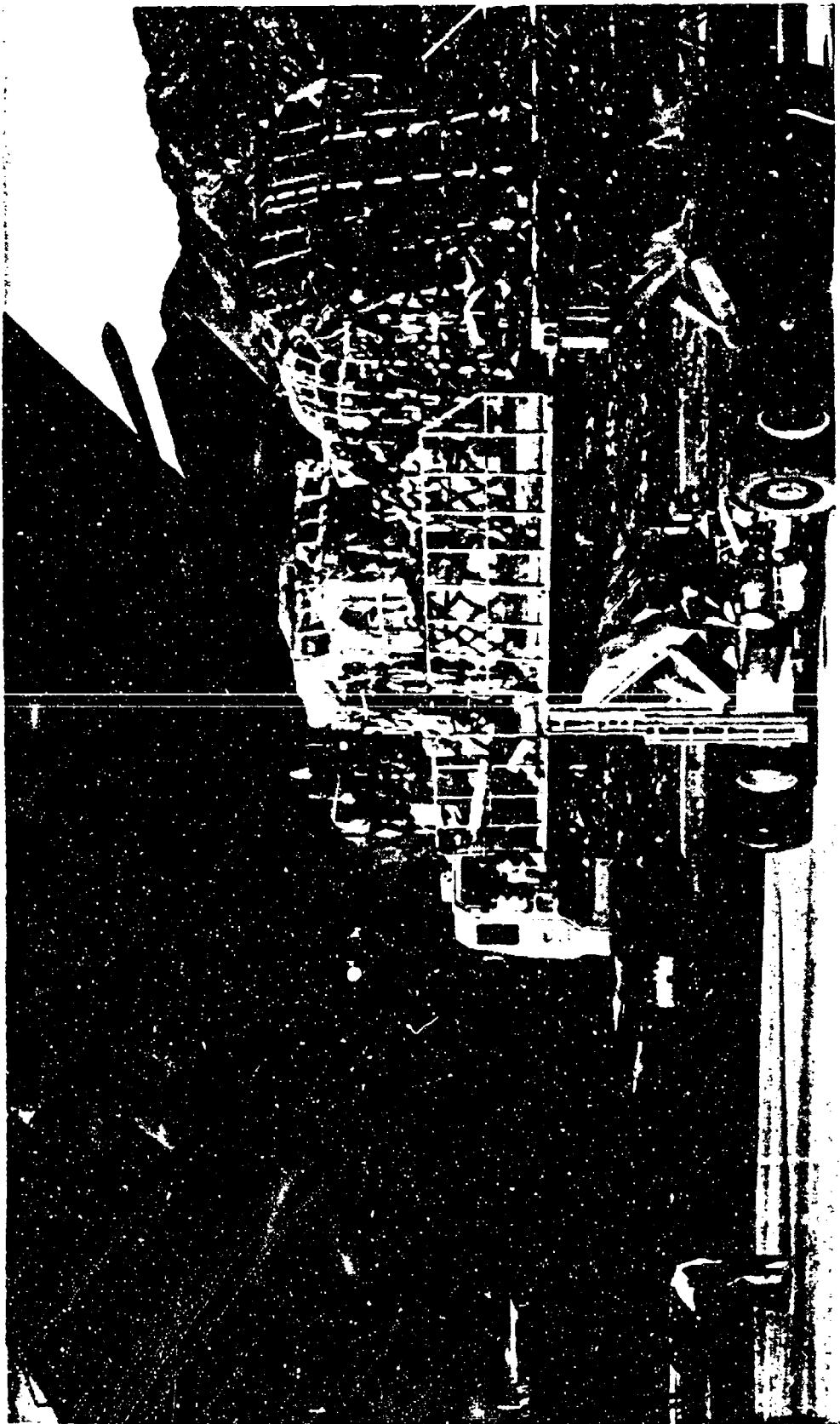
Figure 16

Air Force 40K Transporter/Loader Loading Cargo into a C-5 Airlifter

Source: 21
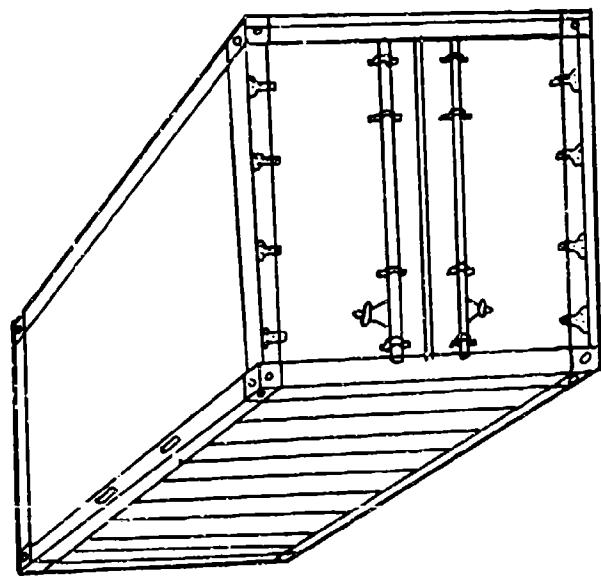
Figure 17

Intermodal Container

Source: 26:451; 35:57

intermodal containers) and pallets. Table 8 is a list of the standard
sizes and maximum gross weights for both the surface and intermodal
containers.

Table 8

Standard Civil Freight Containers

Size (ft) (H x W x L)	Max Gross Weight (lbs) (surface container)	Max Gross Weight (lbs) (intermodal container)
8 x 8 x 10	22,400	12,500
8 x 8 x 20	44,800	25,000
8 x 8 x 30	56,000	
8 x 8 x 40	67,200	
8.5 x 8 x 40	67,200	

Source: 25:581; 26:475

The cargo type has been defined as vehicles, containers, and
pallets. A new cargo system capable of handling vehicles, containers,
and military and civil pallets is recommended. In a detailed design,
the height of the cargo deck would have to be considered to ensure
loading equipment could reach. For roll on/roll off operations, the
loading ramp would have to be designed to ensure that its slope is not
too great for vehicles to drive up. Much of the cargo deck height and
ramp angle would depend on the airship's landing gear type and height.
This study recommends a fore and aft cargo door with straight-in
loading. The LTAV should have a shallow angle loading ramp for Ro/Ro
operations. The aft cargo door can be used for unconventional cargo
delivery methods.

Cargo Delivery Methods

Several cargo unloading or delivery modes are used with airplanes and should be discussed as potential methods for unloading airships. The airland delivery mode involves landing the aircraft and unloading cargo using ground equipment such as forklifts or K-loaders; this is the preferred mode. The assault airland mode is where an airplane would land at an austere, hastily prepared landing zone and rapidly unload. A third mode is the airdrop in which the cargo is dropped out of an airplane by parachute at 1,000 to 1,250 feet above the ground (see Figure 18). A drogue parachute pulls the pallet out of the airplane and a static line pulls the main parachute out. Equipment up to 35,000 pounds can be airdropped. The final delivery mode is by low altitude parachute extraction system (LAPES), or simply, extraction (see Figure 19). In this mode, the aircraft flies at five to ten feet above the ground and a drogue parachute pulls the palletized cargo out. Currently, loads of up to 50,000 pounds can be extracted (2:6-11). The new C-17 will be capable of performing LAPES delivery of outsized cargo up to 55,000 pounds (70).

An airborne delivery mode would be preferable for an airship because the mooring problem would be eliminated. In addition, runways may be rendered unusable by hostile action, thus requiring an airborne delivery mode. An airborne delivery mode would also reduce ground time during which the airship would be vulnerable to attack. If necessary, the airship could land and rapidly unload in a manner and time comparable to a large cargo airplane if the 463L or similar system is used.

Figure 18

Airdrop Mode of Cargo Delivery

Source: 21
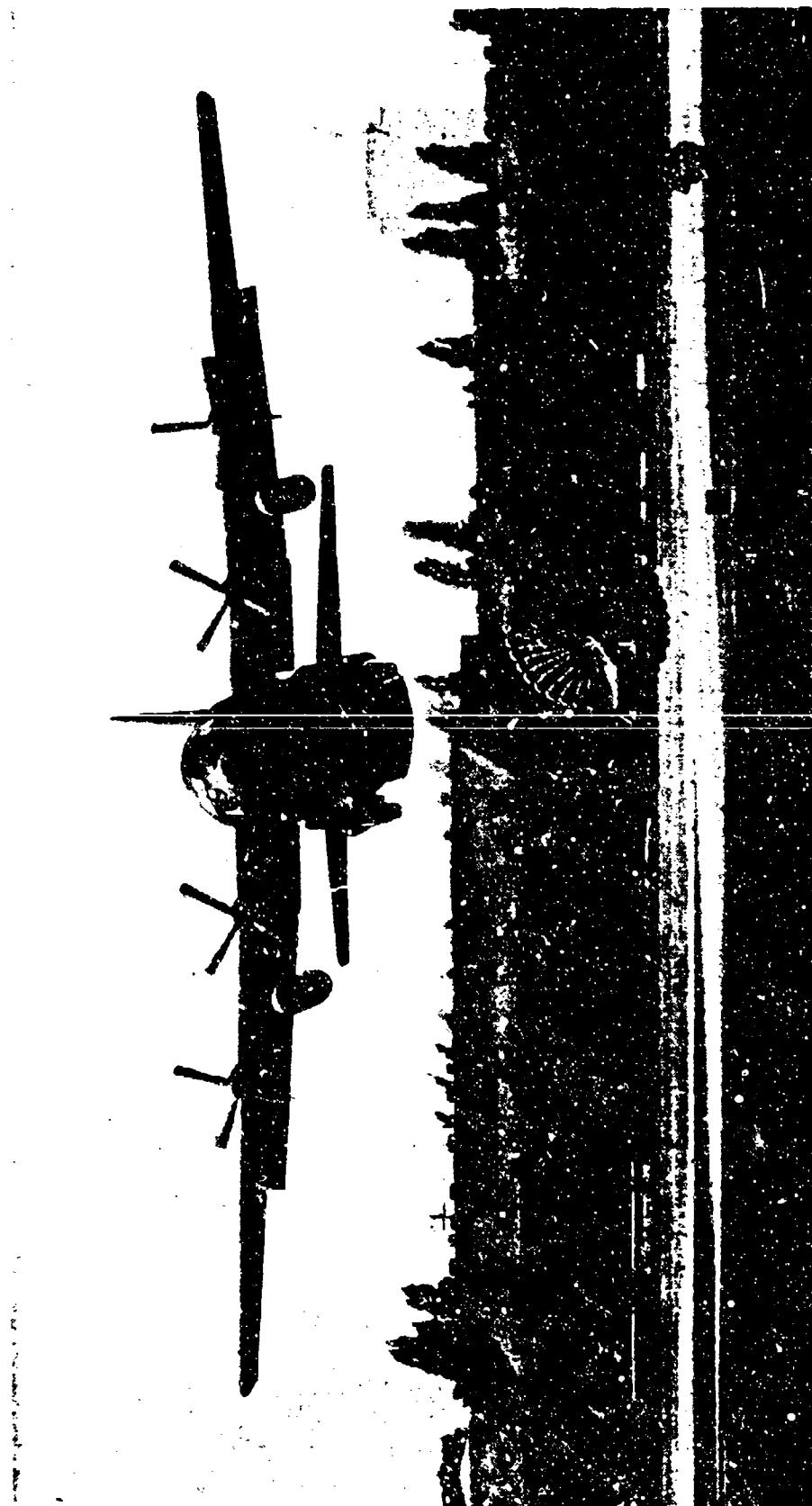
Figure 19

Cargo Delivery by Low Altitude Parachute Extraction System (LAPES)

Source: 21

In Vietnam, the largest Air Force cargo jet, the C-5A, with thirty-six pallets totaling over 200,000 pounds, could be unloaded in approximately thirty minutes (14:57). General Jack Catton, former Commander of MAC, said "There on the ground, when we are vulnerable and the cargo is vulnerable, is when we need the speed most -- a design factor peculiar to our basic role of combat airlift" (14:56).

Maintenance

The U.S. Navy ground handling system developed years ago reduced hangar requirements to major maintenance or to severe weather (32:32). Large airships have the capability of permitting maintenance activity during flight or while moored outside. The Boeing Company had said that its proposed airship for the Navy could be repaired in flight (28:09). Most systems could be housed inside the airship so maintenance could be performed inside the airship regardless of whether the airship was moving or hangared (22:34-35). An engine on the Hindenburg, on at least one occasion, was repaired in flight after suffering a broken piston (32:52-53).

Because the airship would have far fewer and less complex systems than an airplane, maintenance is expected to be lower. In addition, airships are stable and vibration-free in comparison to conventional aircraft. This results in less maintenance due to reduced fatigue (14:24). As a baseline, each flight hour of the C-141 requires about thirty man-hours of ground maintenance (32:53).

Construction Materials

Approximately 30 percent of the gross weight of early airships was due to structures not including the propulsion and fuel systems (22:39; 16:13-14). The structural components of early airships were primarily made of duralumin, an alloy composed of 94 percent aluminum, 4.23 percent copper, and traces of iron, magnesium, manganese, and silicon (16:219). The early structures were (5:2) "very light and efficient, even by present standards. However, this construction was highly complex and labor intensive. . . ." A modern airship would have to be based on much simpler manufacturing techniques. For example, tubular components would be easier to construct than truss-type components. Another possibility is a monocoque design (14:16,17). Such a design is based on a rigid outer shell that eliminates the need for an elaborate skeletal structure except in high load bearing sections (cargo bay). Using new materials will significantly reduce structural weight and possibly simplify the construction process.

> Modern aluminum alloys are 50 to 70% [sic] stronger than the alloys used in rigid airships of the past; newer materials such as nonmetallic composites, have strength/ ' .' ' ratios more than twice as great as that of older alum '... 'loys (43:12).

Carbon fibers appear to be a promising alternative to materials used in the past. Carbon fiber compound (CFC) are a combination of graphite and epoxy, and are extraordinarily strong and fairly inexpensive. They are also easy to work with in the manufacturing process. Table 9 lists characteristics of metals and composites that could be used for airship construction.

Table 9

Characteristics of Construction Materials

	Duralumin	Advanced Aluminum Alloy	High Performance Steel	Graphite/ Polyamide Composite
Density (lb/in^3)	0.10	0.10	0.286	0.056
Modulus of Elasticity (million lb/in^2)	-	10.5	30.0	21.0
Ultimate Strength (thousand lb/in^2)	55	85	280	290

Source: 16:219; 43:13

Examples of CFC uses in modern aircraft are: wing skin for the F-18, the wing of the AV-8B, rudders on the Boeing 757 and 767 and on the Airbus A300-600 and A310. The Lear Fan 2100 is considered the first all CFC airplane. Carbon fiber compounds offer a potential weight savings of 15-20 percent over conventional metals. Another possible material is aluminum-lithium alloys which are 10-15 percent stronger than current alloys and offer greater crack resistance, toughness, and less susceptibility to corrosion (66:23-27). NASA studies have shown a potential weight reduction of up to 30 percent for aircraft using modern materials (32:36-38). One estimate is that new materials can result in weight savings of 25-50 percent in auxiliary structures such as fins, engine nacelles, and crew compartments (43:14). Table 10 summarizes the major advantages and disadvantages of CFC. As shown, the primary disadvantage is elasticity. CFC bend when

placed under a heavy load. This drawback will most likely preclude the use of CFC in the major load bearing section (i.e. cargo bay) of the LTAV. The cargo section would probably require high performance steel.

Table 10

Advantages and Disadvantages
of Carbon Fiber Compounds

	Advantage	Disadvantage
Cost	X	
Crack Resistance	X	
Elasticity		X
Corrosion Immunity	X	
Strength	X	
Weight	X	

Source: 66:23,24,27

Current airships are already taking advantage of modern materials. The Skyship 500 uses a molded one-piece kevlar gondola which is lighter and stronger than conventional aluminum (63:64). The multi-deck, wide-body gondola of the proposed Sentinel 5000 will be built of fiber glass and other composites (69:103). Gas envelopes of early airships were made of heavy neoprene-coated cotton. Present airships use dacron, mylar, or polyester. A 1970s U.S. Navy test LTAV, the High Altitude Superpressured Powered Aerostat (HASPA), used a hull covering made of

mylar film reinforced with kevlar yarn (61:17). In addition to mylar and kevlar, gas envelopes of modern airships could be made of polyurethane. Several authors indicate that these new materials could reduce weight by 40-70 percent in gas cells and related components (5:2-3; 22:25; 43:14; 63:64). In addition, "coating films also have been improved greatly, which will result in a tenfold improvement in gas cell and envelope permeability" (5:3). The outer covering of a modern airship, as on the Skyship 500 and the Van Dusen LTA 20-1, would have to be protected from harmful ultraviolet light which deteriorates most fiber-type material (63:68; 67:734).

Aerodynamics

During the days of commercial airship, sufficient knowledge of aerodynamics was lacking; this was largely due to inadequate wind tunnel technology at the time. According to Arnstein and Klemperer:

> Reynolds numbers of large rigid airships at commercial speeds are of the order of 10^8 to 10^9 and from ten to several hundred times larger than can at present be obtained in model experiments in wind tunnels (6:71).

The following example illustrates the Reynolds number, R_E, of a 1,000 foot long airship moving at 100 miles per hour (147 feet per second) through air having a typical kinematic viscosity of 15.8×10^{-5} ft^2/sec.

$$R_E = V L / v$$
$$= (147 \times 1000) / 15.8 \times 10^{-5}$$
$$= 9.3 \times 10^8$$

This resulting large number is due to the airship's extraordinary

length. The large value indicates the boundary layer is turbulent (28:63,64,246).

Early airship designers had different methods of determining drag on the vehicle. Equation 3 was presented by Arnstein and Klemperer for calculating drag.

$$D = 1/2 \left(C_d \, p \, V^2 \, Q^{2/3} \right)$$

Equation 3

where

$$D = \text{drag (lb)}$$
$$p = \text{density (slug/ft}^3)$$
$$C_d = \text{drag coefficient}$$
$$V = \text{speed (ft/sec)}$$
$$Q = \text{volume (ft}^3)$$

They argued that taking the 2/3 power of the volume is preferable to using the cross section area of the airship hull (6:71). Burgess offered a similar method of determining drag (16:70-71). A Goodyear study for NASA (37:20) offered a drag equation in which some of the terms were powers of the diameter to length ratio. Equation 3 offered the best results when compared to historical airships so it was used as the basis for design calculations in Chapter 4 of this study.

Drag is related to the type of material covering the exterior of the vehicle and to the shape of the vehicle. Modern materials, such as plastics or carbon fiber compounds, can be used to reduce skin friction drag. Loose or wrinkled fabric on older airships accounted for significant skin friction drag (14:17; 32:38). Increased surface smoothness can result in a drag reduction of approximately 10 percent. The 1970s U.S. Navy High Altitude Surveillance Platform for Over the Horizon Targeting (HI-SPOT) was expected to have a drag coefficient of

approximately 0.016 as compared with early rigid airships with drag coefficients of around 0.02. Designers achieved this substantial decrease by maintaining laminar flow over the hull (5:2,31).

Drag also depends on shape, and shape is dependent upon the type of airship. Semirigid and nonrigid airships require internal pressure to maintain their shape. This internal pressure causes them to have a characteristic plump or blunt shape which results in higher pressure drag. The shape of a rigid airship is maintained by the internal structure, not internal pressure. Therefore, rigid airships can be made slender resulting in negligible pressure drag but increased skin friction drag.

For increasing bluntness, pressure drag increases more rapidly than skin friction drag. For this reason, it is more advantageous to keep the airship slender, but this is only possible with the rigid airship. The fineness ratio, the length divided by the maximum diameter, is a measure of the shape of the airships. Airship fineness ratios typically vary from four to eight, with slender, rigid airships usually being greater than six (6:69-71; 16:86; 45:46).

In addition to hull drag, it was found (16:83) that "appendages [such as engine cars, control cars, and mooring gear] forward of the maximum diameter are found to increase the resistance of the hull much more than similar appendages placed aft." It is possible to design the airship so the maximum diameter is more forward and the appendages have more aft area to be located thus reducing drag.

As discussed earlier in this chapter, additional lift can be
achieved by increasing the LTAV's angle of attack. This aerodynamic
lift, however, increases drag. Equation 4, which defines drag due to
aerodynamic lift on an airship, was presented in a Martin Marietta
report (43:59).

$$D_i = (1 - B) \; W \; \sin(a) \hspace{3cm} \text{Equation 4}$$

where

D_i = induced drag (lb)
B = buoyancy ratio
W = gross weight (lb)
a = angle of attack (deg)

For an LTAV with a buoyancy ratio of almost 100 percent, the
amount of induced drag is very small. As an example, the U.S. Navy
ZRCCN, a proposed (20:21) 1.36 million pound airship from the 1940s,
flying at a five degree angle of attack and 95 percent buoyancy has
only about 6,000 pounds more drag than when flying at a zero angle of
attack. Using Equation 3 and somewhat conservative parameters (drag
coefficient = 0.02, speed = 117 fps, density = 0.00237 slugs/ft^3, and
volume = 22,000,000 ft^3), the skin friction drag is computed to be
almost 25,500 pounds. The induced drag was almost 19 percent of the
total drag.

The skin friction drag is proportional to the square of the speed
while the induced drag is not a function of speed. If the speed in
this example is doubled, the skin friction drag would be about four
times as much, or 102,000 pounds, and the induced drag would then only
be about 6 percent of the total drag. Table 11 summarizes this
example.

Table 11

Comparison of Induced Drag and Total Drag
for a Hypothetical Airship

Drag (lb)	Speed = 117 fps	Speed = 234 fps
Skin Friction, D	25,472	101,889
Induced, D_i	5,927	5,927
Total, $D_T = D + D_i$	31,399	103,816
Induced/Total, D_i/D_T	18.9%	5.5%

Notes: $D = 1/2 \, (\, C_d \, p \, V^2 \, Q^{2/3} \,)$
$D_i = (1 - B) \, W \sin(a)$

Assumptions: $C_d = 0.02$ $p = 0.00237 \text{ slugs/ft}^3$
$B = 95\%$ $Q = 22,000,000 \text{ ft}^3$
$a = 5 \text{ deg}$ $W = 1,360,000 \text{ lb}$

Propulsion

Equation 5 provides an accurate estimate of power requirements

(6:80-81).

$$P = (D \, V) \, / \, (550 \, n) \qquad\qquad \text{Equation 5}$$

Combining Equations 3 and 5 yields a detailed power equation.

$$P = 1/2 \, (\, C_d \, p \, V^3 \, Q^{2/3} \,) \, / \, (550 \, n) \qquad \text{Equation 6}$$

where

P = power required (hp)
D = drag (lb)
V = speed (ft/sec)
n = propeller efficiency
C_d = drag coefficient
p = density (slug/ft^3)
Q = volume (ft^3)

Burgess (16:12-14,25⁵) offered other methods of determining power

requirements but none of the methods approached the accuracy of

Equation 6. To verify the accuracy of Equation 6, it was applied to

some early rigid airships. Table 12 shows the values and assumptions

used and the final comparison which verified Equation 6 was acceptable.

Indirectly, this exercise also verified the accuracy of Equation 3.

The airships listed in Table 12 were among the largest every built.

Table 12

Documented and Calculated Power Requirements
For Some Early Rigid Airships

Equation 6 Coefficients	U.S.S. Los Angeles	U.S.S. Sheriandoah	Hindenburg	Graf Zeppelin
Drag Coefficient, C_d	.018	.023	.020*	.020*
Maximum Speed (fps), V	115	91	122	117
Volume ($\times 10^6$ ft$_3$), Q	2.76	2.29	7.65	4.20
Propeller Efficiency, n	58%	42.5%	67%	67%*
Calculated Power (HP), P_C	2,017	1,537	4,490	2,649
Documented Power (HP), P_D	2,017	1,560	4,400	2,800
P_C/P_D	100%	99%	102%	95%

*Engineering assumptions (also assumed $p = .00237$ slugs/ft^3)
Source: 16:86; 32:43; 45:4(

To determine if the drag and power calculations were accurate for

much larger airships, such as the one under consideration for strategic

mobility, a proposed Goodyear airship from a NASA study was analyzed.

Their proposed airship would have been almost 40,000,000 ft^3 in volume. The power requirement estimated by Goodyear (12:4,122) was 80,000 horsepower. Using Equation 6, the power required was estimated to be 85,389 horsepower, or within 7 percent of the Goodyear estimate. Therefore, the basic drag and power equations (Equations 3 and 4) appear to be valid even for airships several time larger than any previously built.

The most important term in both the drag and power equations is speed. Power requirements are proportional to the third power of speed. Therefore, for increases in speed, the power requirements, and hence, fuel consumption, increase exponentially (see Figure 20). To attain higher speeds dictates an increased propulsion system and fuel weight, and consequently requires a corresponding increase in volume of the lifting gas. However, from a designer's point of view, speed is the simplest term in Equation 6 to manipulate. A computer program was written to calculate the power and velocity from Equation 6, and then to plot the curve in Figure 20. The program can be found in the Appendix, Figure A-1.

For a given cruising speed, power requirements decreases with increasing altitude. Specific fuel consumption increases with higher altitude for constant power applications but this increase is small. Ultimately, airships are more fuel efficient when operated at their ceiling (6:87). Turboprop and diesel engines appear to be the only practical propulsion system for a large, modern airship. Turboprops have characteristics such as durability, reliability, low cost, and

Power Vs. Speed for a Potential LTAV
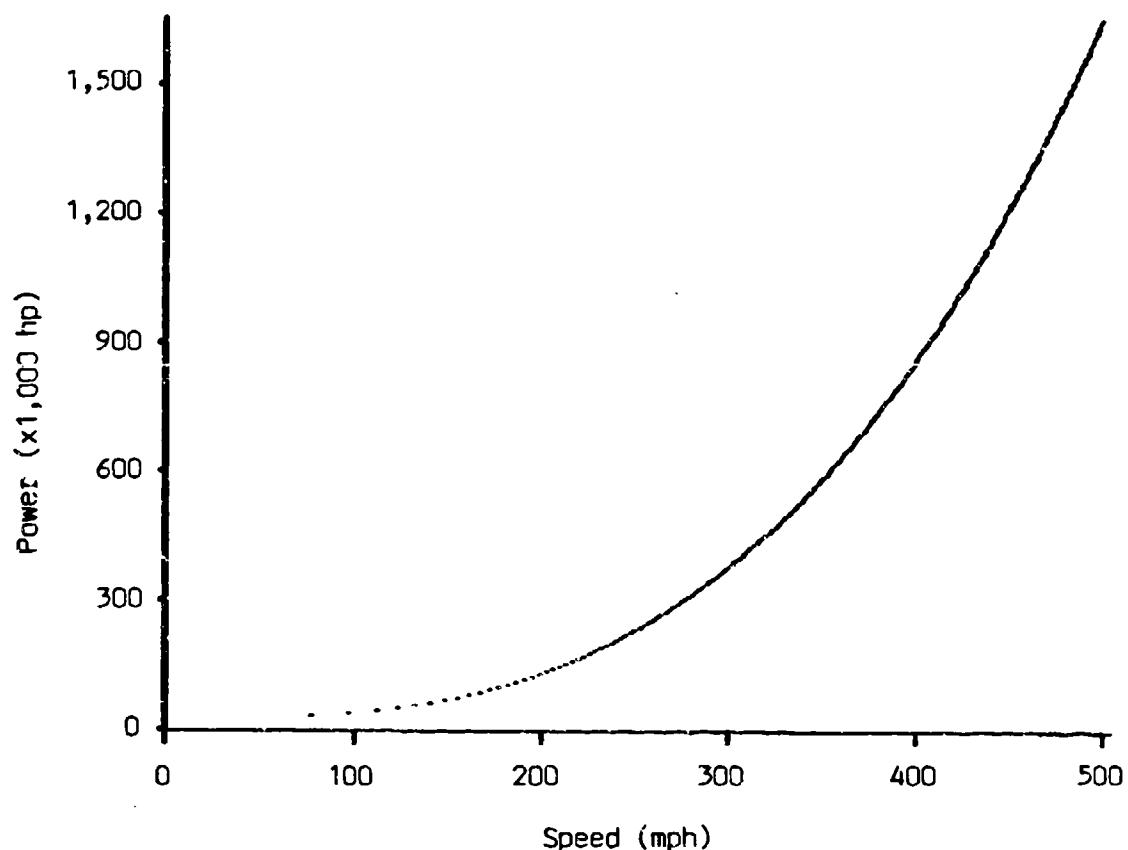
$$P = \frac{C_D \rho V^3 Q^{2/3}}{1100n}$$

Assumptions: $C_D = .02$, $\rho = .00237$ slugs/ft^3, $Q = 25 \times 10^6$ft^3, $n = .9$

Figure 20

Power Vs. Speed for a Potential LTAV

high power to weight ratio. They are readily adaptable for use in airships (32:41,43). The main disadvantage of the turboprop engine is the high specific fuel consumption of gas turbine engines. The diesel engine has characteristics similar to the turboprop except the engine has a much lower power to weight ratio but the specific fuel consumption is about three-quarters that of the turboprop (43:17).

Range, Endurance, Fuel, and Dynamic Lift

According to Ardema (4:89), an aircraft's range is a function of the aircraft's initial weight and the final weight as a result of fuel consumption. Equation 7 describes the range mathematically.

$$R = (V/sfc)(L/D)\ln[m_1/(m_1-m_0)]$$ Equation 7

where

R = range (mi)
V = cruise speed (mph)
sfc = specific fuel consumption ($lb_{fuel}/(hp\ hr)$)
L/D = lift to drag ratio
m_1 = initial total aircraft mass (lb)
m_0 = initial mass of fuel (lb)

In powered airplanes that achieve lift from aerodynamic forces, power is used for forward motion which in turn produces lift on the airfoil. For an airplane in straight and level flight, Equation 8 explains the relation between lift and weight.

$$W = L = 1/2 (C_L \, p \, V^2 \, A)$$ Equation 8

where

W = weight (lb)
L = lift (lb)
C_L = coefficient of lift
p = density ($slug/ft^3$)
V = speed (ft/sec)
A = surface area of airfoil (ft^2)

For a given lift coefficient, density, and wing area, the required lift to support the airplane is proportional to the square of the velocity. Power required decreases as lift requirements decrease; in other words, as the airplane weight decreases due to fuel consumption, power can be reduced which in turn reduces fuel consumption.

For airships in straight and level flight, lifting gas supports the weight of the vehicle, therefore, Equation 8 is not valid. Power required is only that amount to achieve the desired cruising speed. The range of an airship is merely speed times endurance. Equation 9 defines endurance.

$$E = m_0/(sfc \times P)$$

<div align="right">Equation 9</div>

where

$$E = \text{endurance (hr)}$$
$$m_0 = \text{initial mass of fuel (lb)}$$
$$sfc = \text{specific fuel consumption (lb}_{fuel}/(hp\ hr))$$
$$P = \text{power (hp)}$$

This equation assumes no aerodynamic lift is produced. If aerodynamic lift is produced by the hull as it moves forward through the air, the resultant induced drag (discussed earlier in this chapter) requires an increase in power to keep a constant airspeed. This power increase results in increased fuel consumption with a corresponding decrease in range.

During the 1924 flight trials of the U.S.S. Los Angeles, aerodynamic lift of over 10,000 pounds was attained in some instances (6:102). Aerodynamic lift of as much as 12 to 15 percent of the aerostatic lift is possible (64:17). As discussed earlier in this chapter, aerodynamic lift can be controlled by pitch changes. The

airship under consideration in this study may need to rely on
aerodynamic lift for special situations: increase in airship weight
due to loss of lifting gas or addition of load in flight, or terrain or
obstacle clearance. Otherwise, aerodynamic lift will be considered
undesirable due to the resulting induced drag.

Security and Military Threats

No transportation vehicle is immune from every type of hostile
action that may be directed against it. Certain measures can be taken
to reduce threats. Operational security procedures are actions related
to how the vehicle is used. The airship operator (i.e. the military)
would implement these procedures. The LTAV manufacturer would consider
technological security in the vehicle design and construction. Tech-
nological security involves making the vehicle safe and giving it the
means to defend itself from attack.

Operational Security

The manner in which the vehicle is employed can decrease the
threat to a certain extent. The user can establish procedures that
minimize knowledge of or accessability to the airship by hostile
forces. Some operational security measures are: physical security at
the landing site, classified flight plans, use of escorts during
transit flights, and remaining clear of combat zones.

While moored at a base, the LTAV should be guarded just as mili-
tary airplanes are guarded. When the LTAV deploys to an area of actual
or potential military conflict, classified flight plans should be filed

to prevent disclosure of aircraft type and mission. Air routes should be selected to avoid potentially hostile air, surface, and sea traffic. If security cannot be ensured during the transit flight, then it may be practical to use some type of escort. Airplanes escorting LTAVs in a convoy is not unlike the airships of WWII escorting surface ships. An Airborne Warning and Control System (AWACS) aircraft with its long-range radar could fly orbits along the route that several airships would take and provide threat warnings to the airships if unfriendly forces were detected within threatening distances.

At the landing site, it would be logical to expect that friendly forces maintain control of the air and ground, and that threats from enemy aircraft and ground forces would be minimized. Currently there are arguments in the military, in congress, and in the aerospace industry, about allowing cargo jets (costing between $50 and $100 million) to land and unload in the battle zone. General Jack Catton, former Commander of MAC, explained that "the C-5 is a scarce and valued resource because of its airlift capability, and, for that reason, is limited to the amount of risk acceptable (14:54)." Most likely these expensive airlifters will land and off-load their cargo in more secure, rear areas. Lighter-than-air vehicles should also be unloaded in more secure, rear areas.

Technological Security Measures

Defensive measures can be included in vehicle design or added equipment. Navy officials confirm that new airships could be made of plastic or nonmetallic structures to provide stealth characteristics.

The Boeing Company had proposed such a plastic airship to the Navy to perform airborne early warning duties (38:C9). Additionally, the shape of the airship is conducive to lowering the radar cross section; there are not a lot of sharp corners as found on airplanes. Skolnik points out that "materials such as carbon-fiber composites, which are sometimes used in aerospace applications, can further reduce the radar cross section of targets as compared with that produced by highly reflecting metallic materials (65:37)." In addition, radar cross section is reduced if the surface roughness is small compared to the radar wavelength (approximately 5mm to 1m) (65:7,37). With lower radar cross sections, the probability of detection by radar is diminished.

Even if airships are detected by hostile radar, there are several means of confusing the radar. One anti-radar technique involves an electronic device which causes the radar report to appear in a false location. An inexpensive radar jamming method is chaff in which large amounts of small metal strips are dropped to cause false radar reports or to confuse a radar-guided missile. Other missiles can home in on the heat emitted by the aircraft's engines. Two successful countermeasures to this problem have been developed. One involves ejecting flares which the missile will follow. The other countermeasure requires devices on the engines that cause the infrared signature to be disguised. Martin Marietta has proposed (43:102) reducing the infrared signature by equipping the engines with water (ballast) recovery apparatus which will cool the exhaust gas.

In the event that no countermeasures work and the airship is hit, it may not necessarily be a loss as most airplanes would be. A study of 337 World War I combat missions by airships showed that sixty-four missions resulted in losses of the airship, but only fifty airships were lost due to enemy action. One French airship was hit 1,300 times with machine gun fire and still returned home. A German airship was hit ten times in the hydrogen gas cells and returned safely. Another German airship was strafed for twenty minutes with machine guns and survived (14:45).

An airship has six major subsystems susceptible to damage: the hull structure, the gas cells, the control surfaces, the propulsion systems, the fuel/oil subsystems, and the key personnel stations. Of these subsystems, only a catastrophic failure of the hull would result in a sudden loss of the airship (22:54-55). Separate gas cells would improve the probability that one explosion would not cause the sudden loss of most of the lifting gas.

A proposed U.S. Navy airship for the 1940s, the ZRCV (20:20), was designed to have twenty-five gas cells. This design allowed for only a four percent loss of lift if one cell was ruptured. If two cells were ruptured, the loss of lift could have been made up with dynamic lift. The loss of two additional cells could have been compensated for by jettisoning all ballast. This same design could be incorporated in a modern airship. In addition, a vectored thrust propulsion system could be tied to the automatic flight control system to provide differential steering if control surfaces are damaged. Separating a sufficient

number of engines on the airship would ensure that a single explosion

would not cause a total loss of all propulsion. Airplanes, on the

other hand, may easily have adjacent engines damaged, and then the

asymmetric thrust from the opposite wing can cause difficulty in main-

taining controlled flight. Self-sealing fuel tanks, having been proven

on combat aircraft, can be used on airships to prevent loss of fuel and

the subsequent fire hazard if fuel tanks are ruptured. Separate cock-

pits might be a practical solution for protecting the crew and also for

providing redundant flight control systems.

Comparison with Ship and Airplane Vulnerabilities

The airship, the surface ship, and the airplane, each have their

own vulnerabilities and advantages. Although the surface ship is slow

and would be easy to detect, it can suffer enormous assaults and still

survive. Many commercial ships attacked in the Persian Gulf during the

Iran-Iraq War serve as examples. On the other hand, airplanes have the

speed to reduce detection and interception. Once they are attacked

relatively little damage could spell disaster for the airplane. This

is due primarily to the high density of critical subsystems on board

airplanes. The airship is large enough that critical subsystems can be

dispersed throughout the hull so one hit would not destroy several sub-

systems or backup systems (32:55; 64:49). Some authors believe airship

vulnerability falls between the airplane and the surface ship with the

airplane being the least vulnerable (32:57).

Anti-runway weapons can be employed against airfields leaving an

airlifter with no place to land at its destination. Likewise, seaports

could be attacked resulting in damage to the port facilities that make unloading ships extremely difficult. The airship has the capability to unload cargo by aerial delivery methods. These methods do not require sophisticated facilities at the destination; the airship only requires a relatively flat area to fly over and drop the cargo.

CHAPTER 4

Costs of Strategic Mobility LTAVs

LTAV Fleet Size and Uses

Before the cost of a modern airlift airship can be determined, the size of the fleet would have to be known. The size of any potential commercial fleet should also be considered since the technological differences between military and commercial versions may not be too great and total development costs might be shared. A study by Booz-Allen for NASA shows a market for heavy lift airships to exceed 1,000 vehicles (45:50). Another author suggests 2,000 airships operating by the end of the century is not unreasonable (60:57). One Canadian lumber company has indicated that it could use fifty LTAVs for carrying trees from undeveloped areas.

Other commercial uses for airships include performing surveys, patrolling pipelines and electrical power lines, transporting natural gas, petroleum, and ore, transporting portable hospital units, erecting modular houses, and monitoring pollution and environmental conditions (12:66; 81:24). The LTAV has a chance to meet a demand in commercial transportation that is still unfulfilled. Figure 21 highlights a gap in transportation systems in terms of vehicle speed and shipping cost. The airship might possibly fill this void as an economic alternative to current transportation modes. Some advocates feel a transportation revolution would be triggered if a large LTAV program was initiated.

91
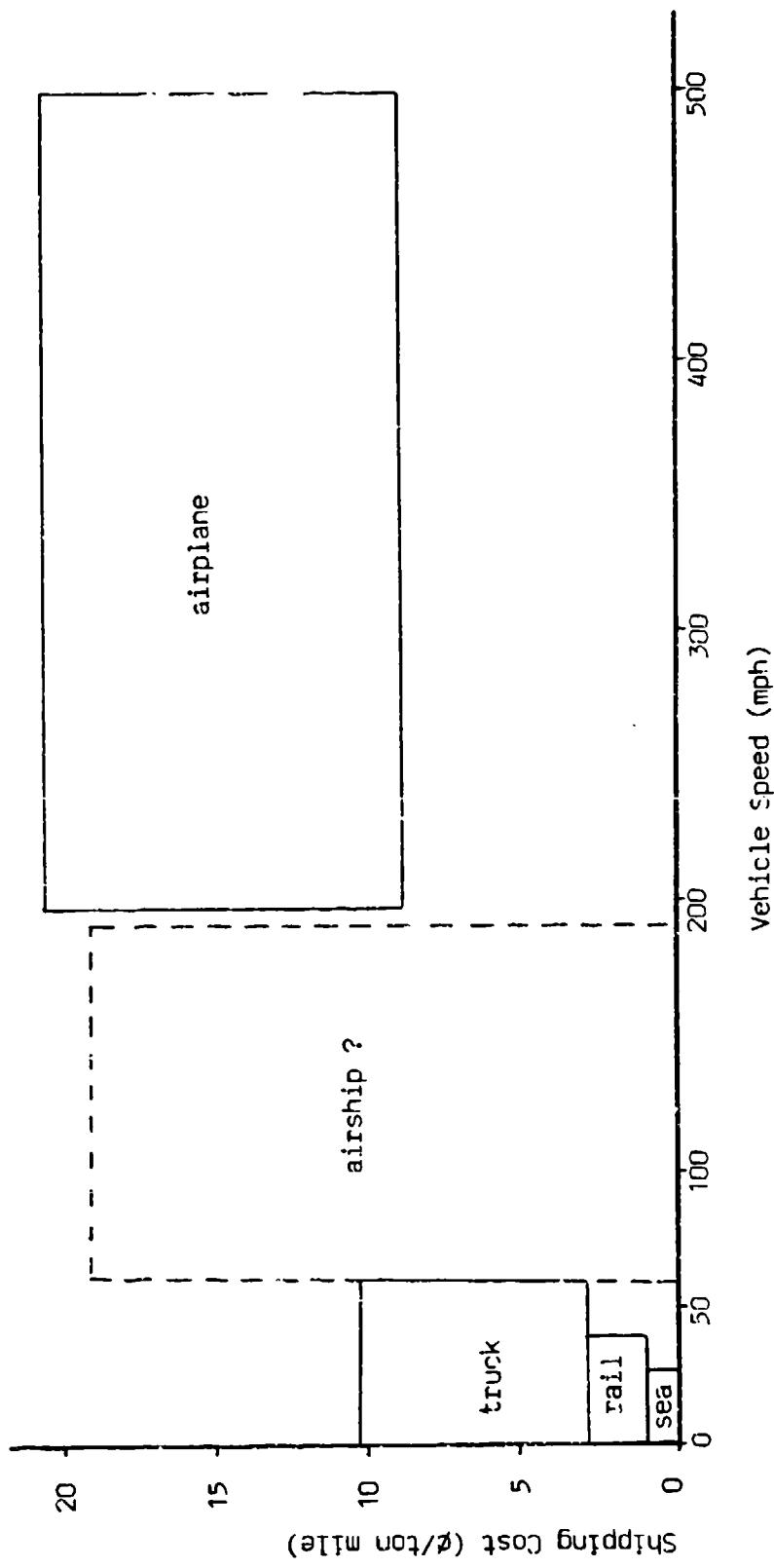
Figure 21

Shipping Costs and Speeds for Different
Vehicles (1975 $)

Source: 1:20-21; 12:28; 81:29

LTAV Economic Studies

It is very difficult to determine the costs associated with the design, construction, and operation of large airships today. The most current data available is for small nonrigid or semirigid airships. The only valid data for rigid airships is from the 1930s (81:27). Some recent feasibility studies have shown that heavy-lift hybrid airships are efficient and cost-effective (72:425); however, hybrids require so much research, development, test, and evaluation (RDT&E) to prove the concept that their cost appears prohibitive (32:46). This may lead to a more conventional airship design. To date, the largest airships ever built were the Hindenburg and its sistership, the Graf Zeppelin II, both over 800 feet long with a gas volume over seven million cubic feet.

> Yet many analysts feel that a 10,000,000 cubic foot airship is the smallest that would be commercially feasible today. Some even talk of 50 to 100 million cubic foot airships, 1,800 to 2,500 feet long (81:25).

A joint NASA-Navy study (45:49-50) analyzed conventional rigid LTAVs up to forty million cubic feet in volume, approximately the size proposed in this study. The study presented 1978 costs for an 11.2 million cubic foot rigid airship. Table 13 summarizes the cost estimates. The study was based on acquisition of ten airships and assumed a twelve year life cycle. The RDT&E costs included the propulsion system, airframe, avionics, spares, and facilities. In contrast to the NASA-Navy study, Lockheed estimated that it would cost them between

$1.3 and $2.9 billion (in 1975 $) to develop a heavy lift cargo airplane. This estimate is probably accurate for other aircraft manufacturers.

Table 13

NASA-Navy
Estimated Airship Costs (1978 $)

RDT&E Costs	$ 784.0 million
Total Production Costs (10 LTAVs)	$ 543.0 million
Training and Facilities Costs	$ 9.8 million
Operating Costs (12 years)	$ 67.1 million
Total	$1,403.9 million

Source: 45:50

A McDonnell Douglas study (53:65-66) of future airlift vehicles predicted acquisition costs of $20 to $40 billion and life cycle costs of $50 to $100 billion for nuclear-powered aircraft, wing-in-ground effect vehicles, distributed load vehicles, and propfan and turbofan aircraft. A modern airship program would use many recently developed aerospace techniques, procedures, and materials. Development costs, therefore, should not be as high as development costs for a program that is pushing the limits of technology.

The Navy is currently looking at a fleet of fifty airships for airborne early warning missions in a $3.3 billion [acquisition] program" (38:C9). At $66 million each, these airships would be almost

half the cost of the Boeing Airborne Warning and Control System (AWACS)
airplane. These LTAV would have extensive electronic capabilities that
a cargo airship would not need. The cost for a cargo airship should be
substantially lower than $66 million; however, Dr. A. D. Topping
(64:42) of Goodyear predicted that a U.S.-built 1,200 foot long airship
would cost about $50 million in 1970 dollars. This can be compared to
the costs for current cargo airplanes listed in Table 14. The average
cost per pound (empty weight) of the cargo aircraft listed in Table 14
is just over $280.

Table 14

Approximate Costs for Cargo Airplanes

Airplane	Empty Weight (lbs)	Cost	Cost/lb
Boeing 747 Freighter	342,000	$ 58 million	$170
Lockheed C-5B	333,000	$ 98 million	$294
McDonnell Douglas C-17	259,000	$100 million	$386
McDonnell Douglas KC-10	240,000	$ 74 million	$308

Source: 5:41; 49:76; 56:49; 62:38; 68:442; 78:119; 80:116

Potential Government Support

Because the military budget is encountering substantial cutbacks,
the strategic mobility LTAV may never become a reality. The military
airlift money will be spent on more conventional systems. The U.S.
Navy program for airborne early warning (AEW) LTAVs addresses only some

of the technological aspects of an airlift LTAV. This is due to the
difference in design; the AEW LTAV is not designed for heavy lift and
is not a rigid airship.

If the military does not pursue an airlift LTAV program, it is
doubtful that industry will. Without government backing, the invest-
ment and the risks to industry are too high. In the early 1970s, many
aircraft manufacturers did not have the capital to undertake new large-
scale aircraft design programs (64:33; 61:29). In addition, aerospace
firms are reluctant to put the required capital into a program, such as
LTAV, that appears to be going backwards in technology.

CHAPTER 5

Proposed Strategic Mobility LTAV

Previous chapters have qualitatively identified some important features and concerns that must be addressed in a strategic mobility LTAV. This chapter will present quantitative analysis to assess whether airships can be competitive with the current strategic mobility fleet of airplanes and surface ships. The new C-17 airlifter will also be included in the analysis although it is still under development. This competition is not intended to show that airships can replace the current vehicles but is meant only as a baseline for comparison. In addition, this chapter will present physical characteristics of a proposed LTAV for strategic mobility.

Baselines for Comparison

Goodyear defined two figures of merit, or standards of measurement, for a proposed airship to carry heavy outsized equipment. The first figure of merit was simply absolute payload, and the second was payload ton miles per pound of fuel (12:95,97). The latter was modified in this study to establish common units (i.e. payload ton miles per ton of fuel). It may also be useful to consider payload ton miles per hour since time is a key factor. However, the surface ship has such a high payload capacity that even with its slow speed, it still far outweighs the airlifters in terms of payload ton miles per hour.

Speed is the significant attribute of the airlifters so a common figure of merit was derived using the vehicle speed raised to a power. Equation 10 shows the speed raised to some undetermined power that must be found in order to give vehicle speed increased significance.

$$(P_s)(V_s)^n = (P_a)(V_a)^n$$ Equation 10

where

P_s = ship payload (tons)
V_s = ship speed (mph)
n = exponent to add increased significance to speed
P_a = aircraft payload (tons)
V_a = aircraft speed (mph)

Equation 10 was solved using realistic values for the payload and speed for both the surface ship (48:773-786) and for the aircraft (82:150), then the exponent was computed.

$$(40,000 \text{ tons})(30 \text{ mph})^n = (120 \text{ tons})(500 \text{ mph})^n$$

Solving the equation gives an exponent, n, of approximately 2. The equation was used to demonstrate that the speed advantage of the aircraft makes up for its fuel and cargo inefficiencies as compared to surface ships. Figures of merit to be analyzed will not consider the surface ship due to its high efficiency. Table 15 shows figures of merit for strategic airlifters.

Related Studies

With the energy crisis of the 1970s, advocates (63:64) began promoting LTAVs for commercial and military use, and "by 1982 various government agencies had spent approximately $4.5 million on thirty-five studies which indicated that the time had come to give LTA[V] another look." Under a NASA contract, Goodyear investigated many

possible uses for modern lighter-than-air vehicles. One of the LTAVs
studied was a conventional rigid airship with a volume of almost forty
million cubic feet and a useful load of 390 tons (12:4). Other parts
of the Lockheed study analyzed requirements of military and commercial
heavy lift airships. Some of the performance requirements investigated
were: 20,000 mile range, speed up to 175 miles per hour, 100 to 200
hour endurance, and payloads up to 2,000 tons (12:75,83-84).

Table 15

Figures of Merit for Strategic Mobility Aircraft

Figure of Merit	C-5	C-141	C-17
Absolute payload (tons)	121	45	86
Payload ton mi/ton$_{fuel}$	1,845	1,705	3,425
Payload ton mph	63,160	25,100	44,460
Payload ton mph^2 (x 10^6)	33	14	23

Source: 18:114,119; 68:442; 82:150,152

An Air Force Flight Dynamics Laboratory study (53:65) of strategic
mobility examined a proposed forty-two million cubic foot airship with
a payload capability of almost 400 tons and a length cf just under
1,400 feet. The airship was designed to achieve 20 percent of its
total buoyancy from aerodynamic lift.

A joint NASA/Navy study (45:49) investigated airships up to forty
million cubic feet. The study chose the rigid airship because its

structural efficiency was greater than other types of conventional airships. Also, the higher fineness ratio (length/maximum diameter) for rigid airships makes them more aerodynamically efficient than semi-rigid or nonrigid airships.

Engineering Assumptions

Several variables that affect an airship's design or performance must be identified. Some of these variables will be assumed to be similar to airships of the 1920s and 1930s since they were the most advanced rigid airships built. Other variables will be changed as a result of be_efits of modern technology.

Atmospheric Conditions

The International Standard Atmosphere (ISA) will be used for appropriate calculations. ISA assumes a temperature of fifty-nine degrees F and a pressure of 29.92 inches of mercury at sea level. The air density at sea level is 0.00237 slugs/ft^3, and the specific weight is 0.0763 lb/ft^3 (28:246). The specific weight of helium is 0.064 lb/ft^3 (16:13).

Lifting Gas Volume

Early airships had a lifting gas volume that was typically 94 percent of the total hull volume (16:42; 37:32). The remaining 6 percent was assumed to be air (16:13-14). The extremely large volumes associated with rigid airships made this assumption accurate. Therefore, the 94 percent value will be accepted for this study. This study

will consider the helium to be 94 percent pure, a typical value for helium when used as a lifting gas (16:13-14).

Structural Weight Reduction

This study will assume a conservative weight reduction of 18 percent (32:36-38). The reduction is based on using carbon fiber compounds and is within the range discussed in many of the references examined in Chapter 3. Historic airships had a structural weight equal to approximately 30 percent of the airship's displacement. This 18 percent assumption reduces the structural weight ratio to 24.6 percent of the displacement allowing a greater payload capability.

$$\text{structural weight ratio} = 30\% - 18\%(30\%) = 24.6\%$$

Drag Estimation

The drag coefficient for typical large rigid airships was on the order of 0.02. This conservative value of 0.02 will be used for this study. Burgess (16:49) provided equations to determine the airship's shape, diameter, and length. Equation 11 defines the diameter and Equation 12 defines the length.

$$d = [(4 \times Q) / (pi \times F \times C_v)]^{1/3} \qquad \text{Equation 11}$$

$$1 = F \times d \qquad \text{Equation 12}$$

where

d = diameter (ft)
Q = volume (ft^3)
F = fineness ratio (length/max diameter)
C_v = prismatic coefficient
1 = length (ft)

The prismatic coefficient is a term that describes the location of

maximum diameter with respect to the total length of the LTAV. Burgess (16:523) gives the range for the prismatic coefficient as 0.53 to 0.88 for a rigid airship. This study uses a prismatic coefficient of 0.65 and a fineness ratio of 6.0 meaning that the length is six times the maximum diameter and that the maximum diameter is about half way between the middle and the nose of the airship.

Propulsion Requirements

The propeller efficiency for the proposed airship is assumed to be 90 percent, a conservative number for modern propellers (32:43; 37:32; 43:6). This study will assume a typical specific fuel consumption of 0.46 pounds of fuel per horsepower per hour and a power to weight ratio of 4.5 horsepower per pound (79:148-149). Power requirements will be based on cruise power, or 80 percent of the maximum available power.

Range and Fuel Requirements

This study will assume a range of 8000 miles (57:156-157). Such a range is adequate, assuming a zero wind situation, to fly unrefueled from the central US to the Persian Gulf or to the Philippine Islands (see Figure 22), unload cargo, and fly to a safe refueling base away from the immediate conflict. Equation 13 defines fuel requirements.

$$m_0 = (sfc \times R \times P \times k)/V \qquad \text{Equation 13}$$

where

m_0 = initial fuel requirement (lb)
sfc = specific fuel consumption ($lb_{fuel}/(hp\ hr)$)
R = range (mi)
P = power (hp)
k = 1.47 ft hr/(mi sec) (conversion factor)
V = speed (ft/sec)
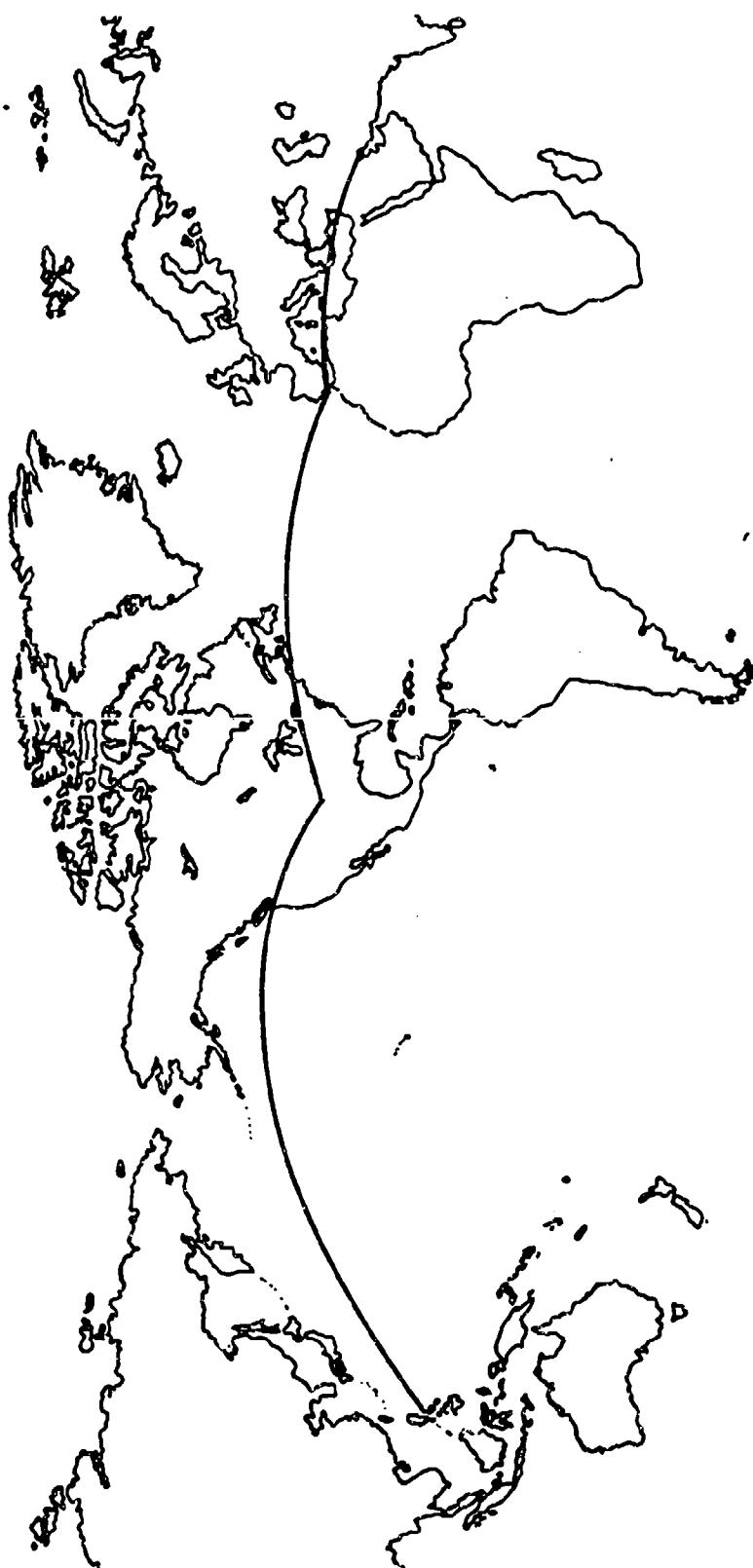
Figure 22

Proposed Range for Strategic
Mobility LTAV

Source: 77

Crew and Provisions

The crews of early airships were large compared to airplanes. The Hindenburg's flight and maintenance crew numbered about thirty-five. This figure included mechanics who monitored gas cells, structural component stresses, hull covering, and engine functions. The flight crew consisted of the captain, three watch officers, and two people to operate the flight controls (32:51). Cabin attendants and other service personnel were added for passenger comfort.

Advances in manufacturing processes, computer technology, and automatic flight control systems can reduce the number of mechanics required on a modern airship. A reasonable proposal (32:52) for a modern airship is a crew of thirteen: one captain, four pilots, two communications operators, two engine technicians, two electronics technicians, and two hull and structures technicians. A crew of this size would permit around-the-clock coverage of all systems and reduce the amount of weight required for a large crew and their provisions.

A realistic consumption rate of twenty-five pounds of foodstuffs and water per person per day is assumed. This comes to an average of almost fourteen pounds per hour for the thirteen man crew. The weight of each crew member with baggage is assumed to be 230 pounds (46:31; 76:144). This gives a total crew weight of 2,990 pounds excluding provisions. Equation 14 shows the weight of the crew and provisions.

$$W_C = 2990 \text{ lb} + (14 \text{ lb/hr} \times E) \hspace{2cm} \text{Equation 14}$$

where

W_C = weight of crew and provisions (lb)
E = endurance (hr)

Table 16 summarizes the crew composition and weight allowanc s but does
not include provisions.

Table 16

Summary of Modern LTAV Crew Composition
and Weight Allowance

Crew Position	Number of Members	Weight Allowance for Crew Members and Bags
Captain	1	230 lb
Pilot	4	920
Communications Operator	2	460
Engine Technician	2	460
Electronic Technician	2	460
Hull/Structures Technician	2	460
Total	13	2,990 lb

Source: 32:53; 46:31; 76:144

Ballast

In commercial shipping, ballast is a non-revenue-producing load.
In the case of military airlift, ballast is a militarily trivial load
carried at the expense of military cargo. If an airship can takeoff
without ballast, then it would not waste any of its lifting capability.
It is anticipated that this modern LTAV would be loaded with ballast on
the ground for stability during loading operations. When the LTAV was
loaded to capacity with cargo and ready to takeoff, ballast would be
jettisoned and the vectored thrust engines would assist in the climb.
As fuel was consumed or as atmospheric conditions changed to cause the

airship to become lighter, ballast could be taken on by recovering
water from engine exhaust through the use of condensers. This ballast
taken on after takeoff would not be at the expense of cargo. For this
study, ballast weight at takeoff will be considered to be zero.

Other Subsystems

Several small subsystems are grouped into one category since their
individual weights would not significantly impact this preliminary
design. The subsystems include the auxiliary power unit (an electrical
generator for ground use), instruments, avionics, and the electrical
system. An analysis of cargo airplanes has led to a weight estimate of
ten thousand pounds for all these subsystems together (23:15-26).

Procedure for Approximating Power and Volume

The outcome of this section is to derive power and volume
requirements for an LTAV that meets the prerequisites. Initially, this
section will analyze weights of components that make up the LTAV
(16:13-14). This weight analysis will consider seven general areas:
weight of the gases in the hull, weight of the main structures in the
airship, weight of the propulsion system, weight of the fuel and fuel
system, weight of the crew and their provisions, weight of miscel-
laneous components, and weight of the payload. Knowing the weights
will enable the required volume, and then drag, to be calculated. The
desired speed and the drag will be used to compute the power require-
ments.

The weight of the gases is given by Equation 15 and is a function

of the percentages of gases present and their specific weights.

$$W_g = [r_a + r_h(w_a - w_h)/w_a]W \qquad \text{Equation 15}$$

where

W_g = weight of the gases (lb)
r_a = ratio of air in the total volume = .06
r_h = ratio of helium in the total volume = .94
w_a = specific weight of air = .0763 lb/ft^3
w_h = specific weight of helium = 0.064 lb/ft^3
W = displacement (lb)

Equation 16 uses previously identified quantities to solve Equation 15.

$$W_g = [.06+.94(.0763 \text{ lb/ft}^3-.064 \text{ lb/ft}^3)/.0763 \text{ lb/ft}^3]W$$

$$= 0.212W \qquad \text{Equation 16}$$

This result means that the weight of the gases is equivalent to 21.2

percent of the airship's displacement. The structural weight, as

described earlier in this chapter, is presented mathematically in

Equation 17. The weight of the miscellaneous subsystems has also been

described earlier in this chapter and is defined in Equation 18.

$$W_s = .246W \qquad \text{Equation 17}$$

$$W_m = 10,000 \text{ lb} \qquad \text{Equation 18}$$

where

W_s = weight of structures (lb)
W_m = weight of miscellaneous subsystems (lb)
W = total airship displacement (lb)

An assumption is made that the fuel system hardware has a weight

equal to five percent of the weight of the fuel. This assumption is

based on data in several sources (10:49; 15:A3-A4; 43:74-75). The

weight of the fuel system, including fuel, is presented in Equation 19.

The specific fuel consumption, sfc, was defined earlier in this chapter as 0.46 lb/(hp x hr).

$$W_f = [sfc + .05(sfc)] \times P \times E \qquad \text{Equation 19}$$

$$= [.46 \text{ lb/(hp} \times \text{hr)} + .05(.46 \text{ lb/(hp} \times \text{hr)})] \times P \times E$$

$$= [.483 \text{ lb/(hp} \times \text{hr)}] \times P \times E$$

where

W_f = weight of fuel and fuel system (lb)
P = power (hp)
E = endurance (hr)

Equation 20 displays the previously established propulsion system weight.

$$W_p = (.25 \text{ lb/hp}) \times P \qquad \text{Equation 20}$$

where

W_p = weight of the propulsion system (lb)
P = power (hp)

The total displacement is shown in Equation 21. The terms that have just been defined are substituted into the equation.

$$W = W_c + W_g + W_s + W_m + W_f + W_p + W_1 \qquad \text{Equation 21}$$

$$= (2990 + 14E) + .212W + .246W + 10000 + .483PE + .25P + W_1$$

where

W = total displacement (lb)
W_c = weight of crew and provisions (lb)
W_g = weight of gases (lb)
W_s = weight of structures (lb)
W_m = weight of miscellaneous subsystems (lb)
W_f = weight of fuel and fuel system (lb)
W_p = weight of propulsion system (lb)
W_1 = weight of payload (lb)
E = endurance (hr)
P = power (hp)

The terms in Equation 21 with similar variables can be grouped together and reduced as in Equation 22.

$$W - .212W - .246W = .25P + .483PE + 14E + 12990 + W_1 \qquad \text{Equation 22}$$

$$(1 - .212 - .246)W = (.25 + .483E)P + 14E + 12990 + W_1$$

$$.542W = (.25 + .483E)P + 14E + 12990 + W_1$$

$$W = (.46 + .89E)P + 25.83E + 23967 + 1.85W_1$$

Now equations must be determined for power and endurance. Volume, Q (in ft^3), and displacement, W (in lb), are related (16:13-14) as shown in Equation 23.

$$Q = W/.0763 \text{ lb/ft}^3 \qquad \text{Equation 23}$$

Equation 23 can be substituted into the revised power equation (see Equation 6) to get a new power equation (see Equation 24) as a function of displacement.

$$P = 1/2 \ (C_d \ p \ V^3 \ Q^{2/3}) \ / \ (550 \ n) \qquad \text{Equation 24}$$

$$= 1/2 \ [C_d \ p \ V^3 \ (W/.0763)^{2/3}] \ / \ (550 \ n)$$

$$= 1/2 \ [C_d \ p \ V^3 \ (5.56 \ W^{2/3})] \ / \ (550 \ n)$$

$$= (1/2 \times .02 \times .00237 \times V^3 \times 5.56 \times W^{2/3}) \ / \ (550 \times .9)$$

$$= 266.2 \times 10^{-9} \times V^3 \times W^{2/3}$$

where

    P = power required (hp)
    C_d = drag coefficient = 0.02
    p = density = 0.00237 slug/ft^3
    V = speed (ft/sec)
    Q = volume (ft^3)
    n = propeller efficiency = 0.9
    W = total displacement

One of the criteria of this study, as discussed previously in this chapter, is that power calculations will be solved using 80 percent of the total power available. This results in a coefficient of 1.25 being

applied to Equation 24, thus giving a more specific power equation (see Equation 25).

$$P = 1.25 \ (266.2 \times 10^{-9} \times V^3 \times W^{2/3}) \qquad \text{Equation 25}$$

$$= 332.69 \times 10^{-9} \times V^3 \times W^{2/3}$$

Endurance is now defined (see Equation 26) as, although the trivial case, range divided by speed. The range has been established as 8,000 miles.

$$E = 8000 \ mi/[V \times (3600sec/hr)/(5280ft/mi)] \qquad \text{Equation 26}$$

$$= 11733 \ hr \ fps/V$$

where

$$E = \text{endurance (hr)}$$
$$V = \text{speed (fps)}$$

Now, Equation 22 can be resolved (see Equation 27) into more manageable terms using the power definition of Equation 25 and the endurance definition of Equation 26.

$$W = (.46 + .89E)P + 25.83E + 23967 + 1.85W_1 \qquad \text{Equation 27}$$

$$= [.46 + .89(11733/V)](332.69 \times 10^{-9} \times V^3 \times W^{2/3}$$

$$+ 25.83(11733/V) + 23967 + 1.85W_1$$

$$= (153.5 \times 10^{-9} V^3 + 3.47 \times 10^{-3} V^2)W^{2/3} + 303063/V + 23967 + 1.85W_1$$

Bringing all the terms on one side (see Equation 28) provides a simple equation that can be solved using a computer.

$$0 = W - (153.5 \times 10^{-9} V^3 + 3.47 \times 10^{-3} V^2)W^{2/3} \qquad \text{Equation 28}$$

$$- 303063/V - 23967 - 1.85W_1$$

where

$$W = \text{total displacement (lb)}$$
$$V = \text{speed (fps)}$$
$$W_1 = \text{payload (lb)}$$

A computer was used to solve for displacement given different combinations of speeds and payloads. The computer program that solved for displacement initially started with a speed of 50 mph and was incremented by 50 mph to a maximum of 250 mph. The initial payload was sixty tons, or the equivalent of one M-1 tank (27:79) and was incremented by sixty tons up to a maximum of 360 tons (six tanks). Table 17 lists design values based on the iterations of speed and payload. Figure A-2 is a listing of the computer program used to solve Equation 28. After computing the gross weight, other design parameters such as power and fuel requirements, volume, length, and diameter were computed (see program listing at Figure A-3). From these parameters, figures of merit were computed and compared with appropriate figures of merit for cargo airplanes (see Table 15).

Proposed LTAV Compared to Cargo Airplanes

Table 18 presents figures of merit similar to those for airplanes listed in Table 15. The asterisks in Table 18 indicate satisfactory LTAV figures of merit, or those that are greater than or equal to the lowest airplane figures of merit listed in Table 15. Only those LTAVs listed in Table 18 with speed and payload combinations with three satisfactory figures of merit were considered acceptable as a strategic mobility airlifter. Cost is an important figure of merit and will be discussed later in this chapter. The computer program used to calculate the figures of merit for the LTAV is shown in Figure A-4.

Table 19 summarizes the characteristics of the potential airships. The first two potential airships listed in Table 19 (#1 and #2) appear

Table 17

Computer Generated Listing of Optimum
Airship Parameters for Given Speeds and Payloads

SPEED (mph)	PAYLOAD (tons)	MAX GROSS WGT (tons)	VOLUME (cu ft)	REQUIRED POWER (hp)	REQUIRED FUEL (tons)	LENGTH (feet)	DIAMETER (feet)
50	60	171	4,469,200	648	24	681	113
50	120	302	7,916,120	937	34	824	137
50	180	431	11,284,400	1,187	44	927	154
50	240	557	14,600,260	1,489	52	1,010	168
50	300	683	17,889,910	1,614	59	1,081	180
50	360	807	21,140,240	1,804	66	1,143	190
100	60	500	13,093,050	10,489	193	974	162
100	120	709	18,584,530	13,247	244	1,095	182
100	180	903	23,656,620	15,568	286	1,186	198
100	240	1,087	28,479,690	17,609	324	1,262	210
100	300	1,264	33,132,370	19,478	358	1,327	221
100	360	1,437	37,667,110	21,217	390	1,385	231
150	60	2,804	73,486,230	111,804	1,371	1,731	289
150	120	3,100	81,245,080	119,541	1,466	1,790	298
150	180	3,382	88,636,960	126,686	1,554	1,842	307
150	240	3,652	95,727,390	133,355	1,636	1,890	315
150	300	3,914	102,581,900	139,648	1,713	1,934	322
150	360	4,167	109,226,700	145,615	1,786	1,975	329
200	60	14,235	373,132,400	782,912	7,203	2,975	496
200	120	14,570	381,913,500	795,147	7,315	2,998	500
200	180	14,888	390,039,300	806,386	7,419	3,019	503
200	240	15,198	398,165,100	817,545	7,521	3,040	507
200	300	15,503	406,291,000	828,633	7,623	3,060	510
200	360	15,810	414,416,800	839,644	7,725	3,081	513
250	60	53,885	1,412,451,000	3,714,066	27,336	4,636	773
250	120	54,195	1,420,577,000	3,728,298	27,440	4,645	774
250	180	54,530	1,429,356,000	3,743,645	27,553	4,655	776
250	240	54,865	1,438,139,000	3,758,965	27,666	4,664	777
250	300	55,175	1,446,265,000	3,773,105	27,770	4,673	779
250	360	55,510	1,455,046,000	3,788,365	27,882	4,682	780

Table 18

Computer Generated Listing of
Figures of Merit for a Proposed Airship

FIGURES OF MERIT

Speed mph	Absolute Payload Tons	Payload Ton Miles per Ton of Fuel	Payload Ton mph	Payload Ton (mph)^2 (millions)
50	60 *	28,382 *	3,000	0.2
50	120 *	27,841 *	6,000	0.3
50	180 *	32,966 *	9,000	0.5
50	240 *	37,020 *	12,000	0.6
50	300 *	40,407 *	15,000	0.8
50	360 *	43,382 *	18,000	0.9
100	60 *	2,487 *	6,000	0.6
100	120 *	3,939 *	12,000	1.2
100	180 *	5,032 *	18,000	1.8
100	240 *	5,926 *	24,000	2.4
100	300 *	6,697 *	30,000 *	3.0
100	360 *	7,377 *	36,000 *	3.6
150	60 *	350	9,000	1.4
150	120 *	655	18,000	2.7
150	180 *	927	27,000 *	4.1
150	240 *	1,174	36,000 *	5.4
150	300 *	1,401	45,000 *	6.8
150	360 *	1,612	54,000 *	8.1
200	60 *	67	12,000	2.4
200	120 *	131	24,000	4.8
200	180 *	194	36,000 *	7.2
200	240 *	255	48,000 *	9.6
200	300 *	315	60,000 *	12.0
200	360 *	373	72,000 *	14.4 *
250	60 *	18	15,000	3.8
250	120 *	35	30,000 *	7.5
250	180 *	52	45,000 *	11.3
250	240 *	69	60,000 *	15.0 *
250	300 *	86	75,000 *	18.8 *
250	360 *	103	90,000 *	22.5 *

Note: An * indicates figures of merit that are greater
than or equal to those listed in Table 15 for airplanes.

Table 19

Characteristics of Potential Airships
Based on 8,000 Mile Range

Proposed LTAV	Cruise Speed (mph)	Maximum Payload ($\times 10^3$ lb)	Max Gross Weight ($\times 10^3$ lb)	Volume ($\times 10^6$ ft^3)	Required Power (hp)	Required Fuel ($\times 10^3$ lb)	Length (feet)	Maximum Diameter (feet)
#1	100	600	2,528	33.1	19,478	716	1,327	221
#2	100	720	2,874	37.7	21,217	780	1,385	231
#3	200	720	31,620	414.4	839,644	15,450	3,081	513
#4	250	480	109,730	1,438.1	3,758,965	55,332	4,664	777
#5	250	600	110,350	1,446.3	3,773,105	55,540	4,673	779
#6	250	720	111,020	1,455.0	3,788,365	55,764	4,682	780

feasible. They are within size estimates predicted by airship experts
(14:13-14; 32:26). The remaining four candidates (#3 - #6) grow in
size at an exponential rate as a result of drag and fuel consumption at
the higher speeds. In addition, helium costs for the smal est (#3) of
the four rejected candidates would be almost $14 million (Equation 29).

$$(\text{helium \$/unit vol}) \times \text{required vol} \times \% \text{ vol of helium} \quad \text{Equation 29}$$
$$= (\$35/1000 \text{ ft}^3) \times 414.4\times10^6 \text{ ft}^3 \times 94\%$$
$$= \$13.6 \text{ million}$$

This is compared to just over $1.2 million dollars for helium in the
two slower candidates (#1 and #2). The second potential airship (#2)
listed in Table 19 is considered to be the prime candidate since its
figures of merit are greater than those for the only other acceptable
candidate (#1). Table 20 compares the proposed LTAV with the
Hindenburg and the C-5 cargo jet.

Table 20

Comparison of Aircraft Characteristics

Characteristic	Proposed LTAV	Hindenburg	C-5 Cargo Jet
Maximum Speed (mph)	100	83	571
Maximum Power (hp)	21,217	4,400	250,326
Payload (lb)	720,000	50,000	241,000
Length (ft)	1,385	814	248
Maximum Diameter (ft)	231	135	-
Wingspan (ft)	-	-	223

Source: 14:14; 45:46; 82:150

Table 21 lists the weights of components of the proposed strategic mobility airship. If a mission has a range less than 8,000 miles, then the fuel weight can be reduced and the payload increased by a corresponding amount.

Table 21

Component Weights of the Proposed LTAV

Component	Weight (lbs)
Lifting gas and air	609,300
Structures	707,000
Fuel system	39,000
Powerplant	5,300
Miscellaneous Subsystems	10,000
Empty Weight	1,370,600
Maximum Fuel	780,800
Crew and Provisions	4,100
Maximum Payload (8,000 mi range)	720,000
Maximum Gross Weight	2,875,500

This study was based on the LTAV having a maximum range of 8,000 miles and that it would complement current cargo airplanes, not replace them. Table 22 shows a delivery sequence for an LTAV operating in conjunction with a C-5 to a destination at the LTAV's maximum range. The table is based on only one LTAV and one C-5 each carrying their maximum payload. This assumption results in the C-5 having to make return trips to pick up additional loads of cargo. Within three and a half days (eighty hours), the LTAV cargo deliveries equal the C-5's.

Table 22

Cargo Delivery Times
Based on 8000 Mile Range

Time in Hours	Tons of Cargo Delivered by LTAV	Tons of Cargo Delivered by C-5	Cumulative Tons Delivered
16	0	121	121
48	0	121	242
80	360	121	723

Table 23 presents a sequence similar to Table 22, but the range is only 4,000 miles. Since the LTAV only requires half as much fuel (192 tons) to go half the distance, the payload can be increased by an additional 195 tons. In less than two days (forty hours), the LTAV can deliver 50 percent more cargo than the total C-5 deliveries. Both Tables 22 and 23 assume the C-5 is refueled in flight, but the added complications are not addressed.

Table 23

Cargo Delivery Times
Based on 4000 Mile Range

Time in Hours	Tons of Cargo Delivered by LTAV	Tons of Cargo Delivered by C-5	Cumulative Tons Delivered
8	0	121	121
24	0	121	242
40	555	121	918

The proposed LTAV should have a large enough cargo deck to carry its full potential of cargo when operating at half the maximum range. This would permit maximum efficiency of the LTAV when it is used on shorter routes since it would not have to carry extra fuel. Until a conflict breaks cut, the LTAV could be used on domestic and short overseas routes.

The cargo deck should be able to accommodate nine M-1 tanks or the equivalent weight in containers or pallets. Table 24 depicts the recommended cargo deck layout for the different types of cargo. The required cargo deck area is 200ft x 55ft, or 11,000ft^2. The recommended height is 15ft.

Table 24

Recommended Cargo Deck Layout
for the Proposed LTAV

| Cargo | (Individual Cargo) | | | Maximum Quantity | Cargo Deck Layout (L x W) |
	Length (ft)	Width (ft)	Height (ft)		
M-1 Tank	35	14	14	9	9 x 1 tanks
Container	10	8	8	90	15 x 6 containers
Container	20	8	8	56	8 x 6 containers
Pallet	9	7.3	-	110	22 x 5 pallets
Pallet	10.4	8	-	110	22 x 5 pallets
Pallet	10.4	7.3	-	110	22 x 5 pallets

Note: Maximum payload is based on fuel requirements.
Source: 25:581; 26:475; 27:79; 73:59,62

Estimated Costs for the Proposed LTAV

The average cost per pound (empty weight) of the cargo aircraft was computed to be $280 (see Table 14). For the proposed airship, $280 per pound for 761,300 pounds (weight of structures, propulsion system, fuel system, and miscellaneous subsystems), the cost would be $213.2 million plus an additional $1.2 million for the helium, giving a total cost of the proposed LTAV of $214.4 million each. This cost, while appearing excessive compared to cargo airplanes, is within the range of costs discussed in several airship studies. Whether airships will cost the same per pound as cargo airplanes can be debated.

Maintenance costs for airships are expected to be low due to less structural fatigue resulting from reduced vibration. Fuel costs will be lower than cargo jets because the LTAV does not require power to produce lift. One study (30:43) has predicted hourly operating costs at about $1,700. Another study (5:41) has predicted almost $1,100 per hour. These cost estimates (30:43; 55:40) are less than current year operating costs for the C-5 and the Boeing 747 which are approximately $5,000 and $4,000 respectively. The operating cost per hour should be weighed with the speed of the vehicle and the payload capability to give cost per ton miles. Table 25 demonstrates this cost comparison. The Boeing 747 Freighter is 13 percent greater than the LTAV in cost per ton mile. The only current aircraft that can carry outsized cargo, the C-5, is 70 percent higher than the cost per ton mile for the proposed LTAV.

Table 25

Cost Comparison Between the
Proposed LTAV and Cargo Airplanes

Aircraft	Operating Cost ($/hr)	Cruise Speed (mph)	Maximum Payload (tons)	Operating Cost ($/ton mi)
Boeing 747 Freighter	4,000	600	125	.053
Lockheed C-5	5,000	518	121	.080
Proposed LTAV	1,700	100	360	.047

Source: 30:43; 55:40; 78:119; 80:116

The C-5 has a life expectancy of 30,000 flying hours (68:424). If the LTAV is kept in service for the same number of flying hours as the C-5, then the total cost for the LTAV can be estimated. Research and development costs are included in the initial cost of the aircraft. This is likewise assumed to be included in the cost per pound of conruction for both the airplane and the LTAV. Table 26 shows a cost comparison between the proposed LTAV and the C-5. The life cycle cost of the proposed LTAV is 9 percent lower than the life cycle cost of the C-5. Table 26 indicates that the LTAV is a cost effective means of transportation in a strategic mobility role. As stated previously, the LTAV is not proposed as a substitute for cargo jets, primarily due to its substantially lower speed.

Table 26

Comparison of Total Costs
for the Proposed LTAV and the C-5

	Proposed LTAV	C-5 Cargo Jet
Cost per aircraft ($)	214,400,000	141,000,000
Operation cost per hr times service life ($)	51,000,000	150,000,000
Total Life Cycle Cost	$265,400,000	$291,000,000

Source: 32:60; 56:49

Table 27 compares the total life cycle costs to the total potential amounts of work (payload ton miles) for both the LTAV and the C-5. The table reveals that the proposed LTAV is more cost effective on shorter flights when it can carry more cargo. When the average mission is 4,000 miles, the LTAV's total cost/total work is almost 3 percent higher than the C-5's. The table shows that if the LTAV is only used on maximum range flights, its total cost/total work is almost 60 percent more than the C-5's. Table 27 does not include the cost of aerial refueling support for the C-5. At its maximum payload, the C-5 could not reach destinations further than 1,700 miles without refueling (82:150). Considering the added cost of C-5 aerial refueling support, the LTAV is cost effective in operating costs, life cycle costs, and total cost/total work when compared to the C-5.

Table 27

Comparison of Life Cycle
Costs and Work Done

| | Proposed LTAV | | C-5 |
	8000 mi range	4000 mi range	Cargo Jet
Total Life Cycle Cost ($)	265.4×10^6	265.4×10^6	291.0×10^6
Life Expectancy (flying hrs)	30,000	30,000	30,000
Cruise Speed (mph)	100	100	518
Maximum Payload (tons)	360	555	121
Lifetime Work (payload ton mi)	1.08×10^9	1.67×10^9	1.88×10^9
Total Cost/Lifetime Work ($/ton mi)	.246	.159	.155*

*Does not account for the required aerial refueling support.
Source: 82:150

CHAPTER 6

Conclusion

Summary

This study has examined the feasibility of using lighter-than-air vehicles to supplement the existing fleet of strategic mobility airlifters. The first objective of this study determined that such an LTAV was survivable considering problems that historic airships encountered and how modern technology could reduce the threat.

The second objective considered a specific mission for the LTAV; that is, to deliver outsized cargo to a destination 8,000 miles away without refueling. This analysis calculated physical characteristics of the potential LTAV. The physical characteristics of the potential LTAV were compared to current cargo airplanes as a point of reference. The purpose of the airship is to supplement, not replace, current strategic mobility airplanes. A specific LTAV was selected as the prime candi- date for the strategic mobility mission. Table 28 summarizes the major characteristics of this proposed LTAV.

Much of the potential success of the modern LTAV will be due to benefits of modern technology. More efficient and lighter weight propulsion systems are available. Modern construction materials and techniques will result in safer airships than in the past. State of the art avionics and control systems will allow fewer crew members to manage the many systems on-board the LTAV. Countermeasures can be

employed in hostile environments to allow the airship to deliver

cargocloser to the conflict than surface ships.

Table 28

Summary of Features
of the Proposed LTAV

Group	Feature
Specifications	8,000 mile range with 360 tons of cargo 100 mph cruising speed 13 man crew Helium lifting gas (35.4 million ft^2)
Avionic/Controls	Digital redundant flight control systems using fly-by-wire Digital instruments Weather radar Modern communication systems
Cargo	11,000 ft^2 cargo bay Dual (commercial/military) handling system (pallets, containers, outsized cargo) Power loading winch Low altitude parachute extraction capability Fore and aft (mid) cargo doors Built-in cargo loading ramp
Construction	Conventional rigid design Modern light-weight materials (CFC) Inverted "Y" tail for aft cargo door
Countermeasures	Infrared countermeasures on engines Chaff dispensers Flare dispensers Non-metallic, radar absorbant hull covering
Engine/Fuel	5 turboprop engines with thrust vectoring 1 engine in stern 2 engines on each side 21,220 horsepower total available power 118,200 gal (780,120 lb) fuel capacity Water recovery (condensation) system

The strategic mobility LTAV can take advantagous of thrust vectoring to maintain its position while being rapidly loaded using standardized cargo loading systems. Thrust vectoring would be used to assist in a vertical takeoff thus alleviating the requirement for a large airport-type facility. At the destination, the LTAV could land to unload or perform an airborne cargo delivery. Standard maintenance could be performed in flight due to internal access to its redundant systems. One system could be serviced while the LTAV flew using the remaining backup system.

Due to the lack of accurate and up-to-date cost data, it was assumed that the LTAV would have a construction cost per pound similar to present day cargo airplanes. This assumption led to a construction cost significantly higher than that of current cargo airplanes. When the anticipated operating cost was considered along with the lifetime work potential, the LTAV was only slightly higher than the C-5.

In conclusion, the proposed strategic mobility lighter-than-air vehicle is feasible for carrying outsized cargo at ranges up to 8,000 miles. The LTAV has the speed advantage over surface ships and the payload advantage over cargo airplanes to make it an effective supplement to the current strategic mobility fleet. Table 29 lists the advantages and disadvantages of the proposed strategic mobility LTAV.

Recommendations

One of the most influential factors in determining the size of the airship is the vehicle speed. The speed is one of the advantages over the surface ship and should not be sacrificed. Fuel weight is a

function of speed. For the proposed LTAV (cruising speed of 100 mph,
payload of 360 tons, and range of 8,000 miles), the fuel weight is 390
tons. Alternative propulsion systems which could reduce the amount of
fuel should be analyzed. If the weight of the fuel can be reduced
substantially, then the size, and ultimately, drag, can be reduced.
This, in turn, leads to an additional reduction in fuel. Alternative
propulsion systems include marine-type diesel engines and solar powered
motors.

Table 29

Advantages and Disadvantages
of the Proposed LTAV

Advantages	Disadvantages
large cargo bay size	large vehicle size
large payload capability	ability to avoid detection
relative fuel efficiency	lack of hangars
simple design	lack of adequate ports
speed greater than surface ships	speed lower than cargo jets
in-flight maintenance	uncertain operating costs
relatively low maintenance	uncertain construction costs
modern light-weight materials	low altitude operations
safe (helium) lifting gas	
aerostatic Vs. aerodynamic lift	
airborne delivery methods	
dual cargo capability	

Marine-type diesel engines have a specific fuel consumption much
lower (25 percent) than that of the turboprop engine considered in this
study. However, they have a power to weight ratio much greater (ten
times) than the gas turbine engine (43:17). An analysis of this type

of propulsion system could determine whether the savings in fuel outweighs the added weight of the heavier engines.

The second alternative propulsion system, solar power, has been studied in two Navy LTAV programs (44:7,14,27; 61:34). A solar-powered airplane has already flown but current technology prevents its application in larger aircraft. The efficiency of the solar cells was only 11.6 percent (42:489). An airship has the surface area to mount a large array of solar cells. An aircraft powered by solar energy would have a fixed weight which may or may not be lower than the weight of turboprop engines and fuel. This topic should be studied further.

APPENDIX

128

```
10 '*****************initialize**********************************
20 LPRINT CHR$(18);      ' set graphics mode
30 LPRINT CHR$(27);CHR$(20);    'set condensed font style, 1600 dots per line
40 DIM PWRSPD(550)     'set up array to hold print head address for each spd
50 '****************calculation routine***********************
60 YFLG=1                     'set flag to print first line of y axis
70 YMAX=270                   'max y axis value
80 YCTR=INT(YMAX/2+2)             'determine center of y axis + 5
90 FOR YCOOR=YMAX TO 0 STEP -1          'ycoor = power
100    GOSUB 220          'print vertical axis
110 '     ******* calculation #1 **********
120      PWR=YCOOR*14*430   ' power
130      SPD=CINT(4.25*(PWR^(1/3)))  'spd=f(pwr)
140      PWRSPD(SPD)=130
150    GOSUB 350
160 NEXT YCOOR
170 '*********** close out routines ***********************************
180 GOSUB 420                         'print horizontal axis
190 LPRINT CHR$(18)             'line advance
200 GOSUB 470                          'label horizontal axis
210 END
220 '******************* print vertical axis**************************
230 LPRINT CHR$(27);CHR$(50);CHR$(3)   'next line
240 IF YCOOR/50<>INT(YCOOR/50) THEN 280    'if ycoord is not multiple of 10
250 '****************label vertical axis**************************
260   LPRINT CHR$(27);CHR$(16);CHR$(0);CHR$(185);CHR$(28);CHR$(3);CHR$(224)    'p
rint y axis tick mark
270 '***************** print vertical line***************************
280 LPRINT CHR$(27);CHR$(16);CHR$(0);CHR$(188);  'set left margin to 2 inch
290 LPRINT CHR$(28);CHR$(2);CHR$(255);   'make vertical lines (255) 2 dots wide
300 RETURN
```

Figure A-1

MS BASIC (2.02) Program to Plot Power Vs. Velocity
Curve in Figure 20. (Page 1 of 2)

```
310 '################print dot#############################################
320 SPD=CINT(SPD)          'round the speed to an integer
330 PWRSPD(SPD)=130
340 RETURN
350 XCOL=188+(1*SPD)       'col position for horizontal data
360 N1=INT(XCOL/255)       'msb x address position
370 N2=XCOL-(N1*255)       'lsb x address position
380 FOR RPT=1 TO 4
390 LPRINT CHR$(27);CHR$(16);CHR$(N1);CHR$(N2);CHR$(28);CHR$(2);CHR$(PWRSPD(SPD)
)    'plot data 2 dots wide
400 NEXT RPT
410 RETURN
420 '################## print horizontal axis############################
430 FOR RPT=1 TO 3
440 LPRINT CHR$(27);CHR$(28);CHR$(18);CHR$(27);CHR$(16);CHR$(0);CHR$(188);CHR$(2
8);CHR$(254);CHR$(192);CHR$(28);CHR$(254);CHR$(192)   'print horizontal axis
450 NEXT RPT
460 RETURN
470 '############## label horizontal axis ###############################
480 FOR XAXIS=0 TO 500 STEP 100       'relative axis coordinates
490    XCOORD=XAXIS+188               'transform to absolute axis coordinates
500    N1=INT(XCOORD/255):N2=XCOORD-(N1*255)   'determine coordinate
510    LPRINT CHR$(27);CHR$(16);CHR$(N1);CHR$(N2);CHR$(28);CHR$(2);CHR$(159) 'po
sition printer head and print
520 NEXT XAXIS
530 RETURN
```

Figure A-1

(Page 2 of 2)

```
10 CLS
20 OPEN "R",#1,"\basic\LTAVDTFL",16
30 FIELD#1,4 AS SP$,4 AS PD$,4 AS GW$,4 AS PWR$
40 RCD=1
50 FOR S=50 TO 250 STEP 50     'speed in mph
60 V=S*5280/3600    'convert mph to fps
70 E=8000/S    'endurance in mi, 8000 mi range
80 FOR PL=60 TO 360 STEP 60    'payload wgt in tons
90 WL=PL*2000    'convert payload tons to lbs
100 WC=2990+(14*E)    'wgt of crew & provisions in lb
110 WM=10000    'weight of misc subsystems in lbs
120 RA=.06:RH=1-RA     'ratio of air and helium in hull
125 DEN=.00237    'density in slugs/cu ft
130 WA=.0763:WH=.064   'specific wgt of air and helium in lb/cu ft
140 WG=RA+(RH*(WA-WH)/WA)   'fraction of displacement due to gases
150 WS=.246    'fraction of displacement due to structures
160 SFC=.46    'specific fuel consumption in lb/hp hr
170 CD=.02:N=.9    'drag coefficient, propeller efficiency
175 W=WL
180 Q=W/WA    'vol = displacement/specific wgt of air
190 P=(1.25*(.5*CD*DEN)/(550*N))*(V^3)*(Q^(2/3))
200 WP=.25*P      'wgt of propulsion system in lbs (p=power in hp)
210 WF=SFC*P*E     'wgt of fuel in lbs (e=endurance in hr)
220 WFS=.05*WF      'wgt of fuel systems in lbs
250 D=W-((WP+WF+WFS+WC+WM+WL)/(1-WS-WG))    'difference
270 IF (D<0 AND D>-500!) OR D>0 THEN 320
275 'PRINT S PL TAB(15) W/2000 TAB(25) W/.0763 TAB(40) P TAB(50) (WF+WFS)/2000 T
AB(63) D
280 W=W+1000!:GOTO 180
290 NEXT PL
300 NEXT S
310 CLOSE:END
320 RSET SP$=MKS$(S):RSET PD$=MKS$(PL):RSET GW$=MKS$(W):RSET PWR$=MKS$(INT(P))
330 PUT#1,RCD
335 LPRINT CVS(SP$) CVS(PD$) CVS(GW$) CVS(PWR$)
344 LPRINT "spd  PL" TAB(15) "GW" TAB(25) "vol" TAB(40) "pwr" TAB(50) "fuel" TAB
(63) "diff"
345 LPRINT S PL TAB(15) W/2000 TAB(25) W/.0763 TAB(40) FIX(P) TAB(50) FIX((WF+WF
S)/2000) TAB(63) FIX(D)
350 RCD=RCD+1
360 GOTO 290
```

Figure A-2

MS BASIC (2.02) Program to
Solve Equation 28

```
10 '*** PROCEDURE TO ESTIMATE PARAMETERS OF AN AIRSHIP ***
20 'data file contains max gross wgts for different spds and payloads
30 OPEN "R",#1,"\BASIC\LTAVDTFL",16:FIELD#1,4 AS SP$,4 AS PD$,4 AS GW$,4 AS PWR$
40 'DATA FILE WITH SPEED (MPH), PAYLOAD (TONS), GROSS WGT (LBS), power (hp)
50 LPRINT CHR$(28);CHR$(30);
60 A$=CHR$(27)+CHR$(16):LPRINT CHR$(27);CHR$(20);CHR$(27);CHR$(31);
70 LPRINT "SPEED";A$;CHR$(0);CHR$(54);"PAYLOAD";A$;CHR$(0);CHR$(114);"MAX GROSS"
;A$;CHR$(0);CHR$(218);"VOLUME";A$;CHR$(1);CHR$(51);"REQUIRED";A$;CHR$(1);CHR$(13
5);"REQUIRED";
80 LPRINT A$;CHR$(1);CHR$(225);"LENGTH";A$;CHR$(2);CHR$(38);"DIAMETER"
90 LPRINT "(mph)";A$;CHR$(0);CHR$(60);"(tons)";A$;CHR$(0);CHR$(114);"WGT (tons)"
;A$;CHR$(0);CHR$(210);"(cu ft)";
100 LPRINT A$;CHR$(1);CHR$(45);"POWER (hp)";A$;CHR$(1);CHR$(129);"FUEL (tons)";A
$;CHR$(1);CHR$(225);"(feet)";A$;CHR$(2);CHR$(36);"(feet)"
110 LPRINT "------";A$;CHR$(0);CHR$(54);"------";A$;CHR$(0);CHR$(114);"-------
-";A$;CHR$(0);CHR$(198);"-------------";A$;CHR$(1);CHR$(45);"---------";
120 LPRINT A$;CHR$(1);CHR$(129);"----------";A$;CHR$(1);CHR$(225);"------";A$;C
HR$(2);CHR$(30);"------"
130 FOR RCD=1 TO 30
140 GET#1,RCD
150 V=(5280/3600)*CVS(SP$)     'convert mph to fps
190 'COMPUTE REQ'D FUEL USING ASSUMPTIONS
200 '   RANGE = 8000 MILES, SPEC FUEL CONSUMP = 0.48
210 RF=(.46*CVS(PWR$)*8000/CVS(SP$))/2000     'FUEL REQUIRED (WGT)
220 RQ=INT(CVS(GW$)/.0763)            'VOLUME
230 CV=.65   'prismatic coef
240 F=6     ' fineness ratio (length/dia)
250 DIA=((4*RQ)/(3.14*F*CV))^(1/3)
260 LPRINT USING "####";CVS(SP$);
270 LPRINT A$;CHR$(0);CHR$(72) USING "###";CVS(PD$);
280 LPRINT A$;CHR$(0);CHR$(120) USING "###,###";CVS(GW$)/2000;
290 LPRINT A$;CHR$(0);CHR$(186) USING "###,###,###,###";RQ;
300 LPRINT A$;CHR$(1);CHR$(51) USING "#,###,###";CVS(PWR$);
310 LPRINT A$;CHR$(1);CHR$(135) USING "###,###";RF;
320 LPRINT A$;CHR$(1);CHR$(225) USING "##,###";F*DIA;
330 LPRINT A$;CHR$(2);CHR$(48) USING "###";DIA
340 NEXT RCD
350 CLOSE:END
```

Figure A-3

MS BASIC (2.02) Program to Compute
Airship Parameters

```
10 '***** MS-BASIC (VERSION 2.02) PROGRAM TO COMPUTE LTAV FIGURES OF MERIT *****
20 'DATA FILE WITH SPEED (MPH), PAYLOAD (TONS), GROSS WGT (LBS), POWER (hp)
30 OPEN "R",#1,"\BASIC\LTAVDTFL",16:FIELD#1,4 AS SP$,4 AS PD$,4 AS GW$,4 AS PWR$
40 LPRINT CHR$(20);CHR$(30);
50 A$=CHR$(27)+CHR$(16):LPRINT CHR$(27);CHR$(28);CHR$(27);CHR$(31);
60 LPRINT A$;CHR$(0);CHR$(236);"F I G U R E S   O F   M E R I T"
70 LPRINT A$;CHR$(0);CHR$(156);CHR$(28);CHR$(57);CHR$(45)
80 LPRINT A$;CHR$(0);CHR$(60);"Speed";
90 LPRINT A$;CHR$(0);CHR$(156);"Absolute      Payload Ton      Payload
Payload"
100 LPRINT A$;CHR$(0);CHR$(66);"mph";
110 LPRINT A$;CHR$(0);CHR$(156);"Payload      Miles per Ton      Ton mph
Ton (mph)";CHR$(27);CHR$(30);"2";CHR$(27);CHR$(28)
120 LPRINT A$;CHR$(0);CHR$(168);"Tons";A$;CHR$(0);CHR$(252);"of Fuel";A$;CHR$(1)
;CHR$(183);"(millions)"
130 LPRINT A$;CHR$(0);CHR$(60);"------";
140 LPRINT A$;CHR$(0);CHR$(156);"--------      ------------      ------
--------"
150 FOR RCD=1 TO 30
160 GET#1,RCD
170 '    RANGE = 8000 MILES, SPEC FUEL CONSUMP = 0.46
180 FF=(.46*CVS(PWR$)*8000/CVS(SP$))/2000     'FUEL REQUIRED (WGT)
190 LPRINT A$;CHR$(0);CHR$(60);USING "####";CVS(SP$);
200 LPRINT A$;CHR$(0);CHR$(168) USING "###";CVS(PD$);:IF CVS(PD$)>=45 THEN LPRIN
T " *";
210 FL=CVS(PD$)*8000/FF   'compute payload ton miles per ton of fuel
220 LPRINT A$;CHR$(1);CHR$(3) USING "##,###";FL;:IF FL>=1705 THEN LPRINT " *";
230 PTMPH=CVS(SP$)*CVS(PD$)     'compute payload ton mph
240 LPRINT A$;CHR$(1);CHR$(99) USING "###,###";PTMPH;:IF PTMPH>=25100 THEN LPRIN
T " *";
250 FOM=CINT((CVS(PD$)*CVS(SP$)^2)/100000!)/10 'compute payload ton mph sq
260 LPRINT A$;CHR$(1);CHR$(201) USING "##.#";FOM;:IF FOM>=14 THEN LPRINT " *";
270 LPRINT
280 NEXT RCD
290 CLOSE:END
```

Figure A-4

MS BASIC (2.02) Program to Compute Figures of Merit
for a Proposed Airship

WORKS CITED

1. Adams, Wendell M., Maj. and Maj. L. Karl Gustke. "The potential of the airship as a future transportation system." Maxwell AFB: Air Command and Staff College, 1977.

2. "Airlift employment." MS322 Handout 322-6. Colorado Springs: United States Air Force Academy, 1977.

3. Anderson, Reed M., Maj. "Lighter-Than-Air (LTA) aircraft: economically competitive as a cargo airlift system?" Maxwell AFB: Air Command and Staff College, 1977.

4. Ardema, Mark D. "Economics of modern long-haul cargo airships." A Collection of Technical Papers - AIAA Lighter-Than-Air Systems Technology Conference, AIAA Report no. 77-1192. New York: AIAA, 1977.

5. ---. Missions and vehicle concepts for modern, propelled, lighter-than-air vehicles, NATO Advisory Group for Aerospace Research and Development (AGARD) Report no. 724. N.p.: AGARD, 1985.

6. Arnstein, K., and W. Klemperer. "Performance of airships." Vol. 6 of Aerodynamic Theory. Ed. William Frederick Durand. New York: Dover, 1963.

7. "Backgrounder". N.p.: U.S. Navy Military Sealift Command, n.d.

8. Barraclough, Sir John, Air Chief Marshall. "Lighter than air - airships in peace and war." NATO's Sixteen Nations 29 (Feb. 1984): 105-109.

9. Beaubois, Henry. Airships - An Illustrated History. London: Macdonald, 1973.

10. Bel, J. C., J. D. Marketos, and A. D. Topping. Maritime Patrol Airship Concept Study, Naval Air Development Center Report no. 78074-60. New Orleans: Bell Aerospace, 1978.

11. Blamey, John T., Major. "Strategic mobility." Air Command and Staff College Associate Programs Readings Book. Maxwell AFB: Air Command and Staff College, 1984.

12. Bloetscher, Fred. Summary and Mission Analysis (Tasks II and IV). Vol. 1 of Feasibility Study of Modern Airships, Phase I, NASA Report no. CR-137692. Akron: Goodyear Aerospace Corp., 1975.

13. Botting, Douglas. The Giant Airships. Alexandria: Time-Life, 1980.

14. Bright, Jack W., Major. "Vulnerability of military strategic airlift airships." Maxwell AFB: Air Command and Staff College, 1975.

15. Brown, N. D. Goodyear Aerospace Conceptual Design Maritime Patrol Airship - ZP3G, Naval Air Development Center Report no. 78075-60. Akron: Goodyear Aerospace, 1979.

16. Burgess, Charles P. Airship Design. New York: Ronald Press, 1927.

17. Casper, M. S., ed. Hydrogen Manufacture by Electrolysis, Thermal Decomposition and Unusual Techniques. Park Ridge: Noyes Data, 1978.

18. Chant, Chris., ed. The Presidio Concise Guide to Military Aircraft of the World. Novato: Aerospace Publishing, 1981.

19. Churchill, Winston Spencer. The River War. London: Longmans, Green, and Co., 1899.

20. Clements, E. W., and G. J. O'Hara. The Navy Rigid Airship, Naval Research Laboratory (NRL) Report no. MR-2463. Washington: NRL, 1972.

21. Defense Audio Visual Agency, Still Media Depository. Washington: Department of Defense, n.d.

22. DeVincenzo, William M., Capt. "The LTA: its potential application to a C^3 mission." Maxwell AFB: Air Command and Staff College, 1978.

23. Eliol, L. F., et al. Cost Analysis. Vol. 5 of New Strategic Airlift Concepts. Long Beach: Douglas Aircraft Company, 1979.

24. Elliott, Frank. "Navy proposes blimps to help defend the fleet." Air Force Times, 16 June 1986: 57.

25. Finlay, Patrick, ed. Jane's Freight Containers 1972-1973. New York: McGraw-Hill, 1972.

26. ---. Jane's Freight Containers 1987. New York: Jane's, 1987.

27. Foss, Christopher F., ed. <u>Jane's Armour and Artillery 1986-1987</u>. London: Jane's, 1986.

28. Giles, Ranald V. <u>Schaum's Outline of Theory and Problems of Fluid Mechanics and Hydraulics</u>. 2nd ed. New York: McGraw-Hill, 1962.

29. Gropman, Alan L., Colonel. "The compelling requirements for combat airlift." <u>Air University Review</u> 33, no. 5 (July - Aug. 1982): 2-15.

30. Hammesfahr, Roy D., Capt., and Capt. Thomas R. Hawk. "A comparative economic analysis of a lighter-than-air logistics system." Wright-Patterson AFB: Air Force Institute of Technology, 1973.

31. Hill, L. S. <u>American and Soviet Interest in Airships</u>, Rand Report no. RM-3698-PR. Santa Monica: Rand Corporation, 1963.

32. Hotinski, Richard M., Major. "Lighter-than-air vehicles: a complementary option for strategic mobility." Maxwell AFB: Air Command and Staff College, 1976.

33. Jackson, John E., Lt Cmdr. "Airships for the 1990s?" <u>Naval War College Review</u> 36 (Jan. - Feb. 1983): 56-60.

34. ---. "Lighter than air: an old answer to new problems?" <u>Defense Science and Electronics</u>, May 1984: 70-75.

35. Katz, Harold. "Water transportation." <u>Transportation and Traffic Engineering Handbook</u>. Ed. Wolfgang S. Homburger. 2nd ed. Englewood Cliffs: Prentice-Hall, 1982.

36. Koelling, Gordon W. "Helium." <u>Metals, Minerals, and Fuels</u>. Vol. 1 of <u>Minerals Yearbook 1971</u>. Washington: GPO, 1973.

37. Lancaster, Jon W. <u>Parametric Analysis (Task III)</u>. Vol. 1 of <u>Feasibility Study of Modern Airships, Phase I</u>, NASA Report no. CR-137692. Akron: Goodyear Aerospace Corp., 1975.

38. Lane, Polly. "Boeing is bidding for blimp." <u>Seattle Times</u>, 9 June 1986: C9.

39. Lange, R. H., and J. W. Moore. "Large Wing-In-Ground Effect Transport Aircraft." <u>A Collection of Technical Papers - AIAA Very Large Vehicle Conference</u>, AIAA Report no. 79-0845. Alexandria: AIAA, 1979.

40. Leachman, William D. "Helium." <u>Metals and Minerals</u>. Vol. 1 of <u>Minerals Yearbook 1984</u>. Washington: GPO, 1985.

41. Lightning and Transients Research Institute. Aerospace Vehicle Protection from Atmospheric Electrical Hazards, USAF Aeronautical Systems Division Report no. TN61-74. Minneapolis: Lightning and Transients Research Institute, 1961.

42. MacCready, P. B., et al. "Sun-powered aircraft designs." Journal of Aircraft 20, no. 6 (June 1983): 487-493.

43. Macy, William L. Parametric and Conceptual Design Study of Fully-Buoyant Air Vehicles, Naval Air Development Center Report no. 76013-30. Denver: Martin Marietta, 1977.

44. Marcy, William L., and Ralph O. Hookway. Propulsion Options for the HI SPOT Long Endurance Drone Airship, Naval Air Development Center Report no. 78193-60. Denver: Martin Marietta, 1979.

45. Mayer, Norman J. "Large lighter-than-air vehicles." A Collection of Technical Papers - AIAA Very Large Vehicle Conference, AIAA Report no. 79-0847. Arlington: AIAA, 1979.

46. McGinlay, Thomas C. J., Lt. Cmdr. "Personnel and equipment design concept for a maritime patrol airship (non-rigid) to conduct search, anti-submarine warfare, and airborne mine countermeasures missions." Monterey: Naval Post Graduate School, 1979.

47. McKelvey, John P., and Howard Grotch. Physics for Science and Engineering. New York: Harper and Row, 1978.

48. Moore, John, Capt. RN. ed. Jane's Fighting Ships, 1986-87. London: Jane's, 1986.

49. Morger, Randal E., Major. "Tankers for a thirsty fleet." Air Force Magazine, June 1986: 74-80.

50. Nagabhushan, B. L., and G. D. Faiss. "Thrust vector control of a V/STOL airship." Journal of Aircraft 21, no. 6 (June 1984): 408-413.

51. Nagabhushan, B. L. and N. P. Tomlinson. "Dynamics and control of a heavy lift airship hovering in a turbulent cross wind." Journal of Aircraft 19 no. 10 (Oct. 1982): 826-830.

52. NASA, trans. Dirigibles. Vol. 3 of Collected Works of K. E. Tsiolkovskiy, NASA Technical Translation F-238. Washington: NASA, 1965.

53. Newton, Floyd C. "Strategic airlift vehicle concepts." A Collection of Technical Papers - AIAA Very Large Vehicle Conference, AIAA Report no. 79-0850. Arlington: AIAA, 1979.

54. Obert, Edward F. Internal Combustion Engines and Air Pollution. New York: Harper and Row, 1973.

55. "Operating and Cost Data 747, A300B, DC-10, and L-1011 - First Quarter, 1980." Aviation Week and Space Technology, 14 July 80: 40-41.

56. Perini, Michael B., Major. "Airlift for near and far." Air Force Magazine, Oct. 1964: 44-51.

57. Rand McNally Cosmopolitan World Atlas. New York: Rand McNally, 1957.

58. "Readiness". N.p.: U.S. Navy Military Sealift Command, n.d.

59. Riley, Thomas B. "Modern airship logistics." Logistics Spectrum 17 (Fall 1983): 6-8.

60. Robertson, Frank. "Airships again in demand." Pacific Defense Reporter, Oct. 1983: 57-58.

61. Scales, S. H., and C. B. McComas. High Altitude Superpressured Powered Aerostat (HASPA) Demonstration Program Final Report. Denver: Martin Marietta, 1977.

62. Schemmer, Benjamin F. "Budget cutters are only ones likely to win battle over C-5B/747/C-17 airlift alternate." Armed Forces Journel International 119, no. 11 (July 1982): 38-48.

63. Seidenman, Paul and David J. Spanovich. "Return of the airship." National Defense, July - Aug. 1985: 63-69.

64. Skinner, Hosea L., Lt Col. "Lighter-than-air for logistics." Maxwell AFB: Air Command and Staff College, 1972.

65. Skolnik, Merrill I. Introduction to Radar Systems. 2nd ed. New York: McGraw-Hill, 1980.

66. Sweetman, Bill. Aircraft 2000: The Future of Aerospace Technology. N.p.: Military Press, 1984.

67. Taylor, John W. R., ed. Jane's All The World's Aircraft, 1984-85. London: Jane's, 1984.

68. ---. Jane's All The World's Aircraft, 1983-84. New York: Jane's, 1983.

69. ---. "Jane's All The World's Aircraft Supplement." Air Force Magazine, Dec. 1987: 97-104.

70. "The USAF/McDonnell Douglas C-17 is coming." N.p.: Douglas Aircraft Company, 1985.

71. Tischler, Mark B. and Henry R. Jex. "Effects of atmospheric turbulence on a quadrotor heavy lift airship." Journel of Aircraft 20, no. 12 (Dec. 1983): 1050-1057.

72. Tischler, Mark B., Robert F. Ringland, and Henry R. Jex. "Heavy-lift airship dynamics." Journel of Aircraft 20, no. 5 (May 1983): 425-433.

73. Tuck, Paul D. "A uniform national air-cargo system." Air University Review 33, no. 5 (July - Aug. 1982): 58-67.

74. Ulsamer, Edgar. "Mobility: key to global deterrence." Air Force Magazine, Sep. 1983: 92-101.

75. "USAF/MDC C-17." N.p.: McDonnell Douglas Corporation, n.d.

76. U.S. Air Force. "MAC and the Civil Reserve Air Fleet (CRAF)." Scott AFB: MAC, Feb. 1983.

77. U.S. Army. "World Map." N.p.: Army Topographic Command, March 1972.

78. "U.S. commercial transports." Aviation Week and Space Technology, 8 March 1982: 118-19.

79. "U.S. gas turbine engines." Aviation Week and Space Technology, 8 March 1982: 148-49.

80. "U.S. military aircraft." Aviation Week and Space Technology, 8 March 1982: 116-17.

81. Vitteck, Joseph F., Jr. "Is there an airship in your future?" Technology Review 77, no. 8 (July - Aug. 1975): 22-29.

82. Young, Susan H. H. "Gallery of USAF weapons." Air Force Magazine, May 1986: 143-160.

ERRATA ADA 213574

Bruce J. Gasper
1504 NE 11th Str.
Moore OK 73160

ERRATA

6 Dec 91

DTIC/OCC
Cameron Station Bldg 5
Alexandria VA 22304-6145

Dear Mr. Waltson;

I submitted my thesis "Feasibility of Lighter-Than-Air Vehicles for Strategic Mobility" to DTIC a few years ago for adding to their document library. I recently discovered some obvious errors that I failed to find while proofreading. I would like to add the enclosed errata sheet to the document you have on file. Please let me know if you need anything else from me to correct the errors. Thank you for your cooperation.

Sincerely,

Bruce J. Gasper

1 Encl.
Errata

Errata *AOA 213574*

"Feasibility of Lighter-Than-Air Vehicles for Strategic Mobility"

Page 55, line 10. Change "tons" to "pounds".

Page 118, Table 24, entry 3.

Container	20	8	8	56	8 x 6 containers

should read

Container	20	8	8	56	8 x 7 containers